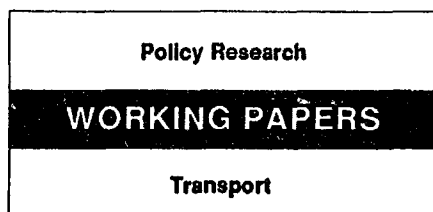


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Congestion Charging Mechanisms for Roads

An Evaluation of Current Practice

Timothy D. Hau

Of the many direct and indirect methods of charging for road use, the key alternatives for reducing road congestion are (1) cordon pricing using manual tollbooths, (2) supplementary vehicle licensing, (3) automatic vehicle identification, and (4) smart card technology.

This paper — a product of the Transport Division, Infrastructure and Urban Development Department — is part of a larger effort in the department to evaluate options to charge for the use of roads. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Jennifer Francis, room S10-063, extension 31005 or 35205 (December 1992, 99 pages).

Hau explores 20 criteria for a “good” road pricing system and presents case studies illustrating the costs, revenues, and benefits of alternative congestion charging mechanisms.

Hau finds that *manual tollbooths* are not suitable for congestion charging because they are land-, labor-, and time-intensive. *Cordon pricing* (as in the Bergen toll ring) can be an effective instrument for charging for congestion if half the toll lanes are reserved for seasonal pass holders traveling through the pricing points at regular highway speed. Enforcement of those driving in reserved lanes can be carried out by periodic videographs of vehicle license plates.

Area licensing schemes require that vehicles entering the central business district during peak hours prominently display a monthly or daily license. Enforcement is undertaken at gantry points by traffic wardens who perform visual checks on the nonstop traffic. The enforcement costs of area licensing schemes are prohibitive at motorway speeds but relatively low-cost in a standard congested urban setting with limited gateways. Area licensing schemes, also known as supplementary licensing, carry the lowest cost per transaction.

Electronic road pricing with automatic vehicle identification (an off-vehicle recording system) is electronic toll collection by time of day *writ large* and made obligatory on vehicle owners in a jurisdiction. The cost of the electronic equipment is not trivial, but is outweighed by the benefits. Sensitivity analysis performed on the Hong Kong electronic road pricing scheme in 1983-85 shows that even after excluding time savings, the savings in operating costs produce benefit figures that are greater than system costs. The invasion-of-privacy issue that led to the political failure of the Hong Kong

electronic road pricing scheme can now be overcome by giving road users access to confidential “numbered account arrangements” with a prepaid cash deposit.

The capital cost of *electronic road pricing with smart card technology* (an on-vehicle charging system) is higher than the cost for automatic vehicle identification technology alone, but benefits still outweigh costs (as in the Dutch proposal). Together, the benefit-cost ratio and the cost per transaction are acceptable but this technology is still not widely used commercially.

Hau argues that electronic approaches to direct road use charging are superior to manual approaches for road users, road authorities, and society as a whole. And rapid progress in microelectronics, cryptology, and microwave technologies will continue to yield large-scale economies in the manufacturing of automatic vehicle identification equipment, read-write transponders, smart cards, and the hardware and software that go with them.

Hau ranks electronic road pricing with automatic vehicle identification alone higher than electronic road pricing with smart card-type AVI based on an unweighted index of all criteria. And generally, the area licensing scheme is superior to cordon pricing. If budgets allow, authorities should investigate the feasibility of electronic road pricing. If the budget is tight, they should look into the area licensing scheme with its low cost and high benefit-cost ratio (the latter being the most important of the 20 criteria Hau uses).

Both conceptually and practically, Hau finds that it is important to earmark the proceeds of road pricing to implement marginal cost pricing in the road sector.

The Policy Research Working Paper Series disseminates the findings of work under way in the Bank. An objective of the series is to get these findings out quickly, even if presentations are less than fully polished. The findings, interpretations, and conclusions in these papers do not necessarily represent official Bank policy.

**Congestion Charging Mechanisms for Roads:
An Evaluation of Current Practice**

by

Timothy D. Hau

**Transport Division
Infrastructure and Urban Development Department
The World Bank**

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I retain full responsibility for any of the views expressed in this paper.

Timothy D. Hau

SYNOPSIS

Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice

by

Timothy D. Hau

This paper investigates the implementation aspects of road pricing by setting down criteria for a 'good' road pricing system. Besides analyzing the gamut of indirect and direct methods of charging for road usage, the paper surveys alternative congestion pricing technologies including: 1) cordon pricing using manual tollbooths, 2) supplementary licensing, 3) off-vehicle recording systems such as automatic vehicle identification, commonly known as AVI, and 4) on-vehicle charging systems such as smart card technology. Each of these instruments is dealt with by a relatively in-depth case study analysis based on the benefits, costs and revenues of implementing and utilizing each charging mechanism. Since benefit figures are not always readily available, the cost per transaction of operating a system over the long run is used as an index of the relative cost-effectiveness of each technology. Based on alternative quantitative and qualitative criteria, the implications of using each of these technologies for tackling congestion are summarized in a key table and conditional policy recommendations are made.

Tollbooths suffer from being land intensive, labor intensive and time intensive and are clearly unsuitable for congestion charging in and of themselves. However, cordon pricing (as in the Bergen Toll Ring) can serve as an effective instrument of charging for congestion if half the toll lanes are reserved for the use of seasonal pass holders traveling through the pricing points at regular highway speeds. Enforcement of those driving on reserved lanes can be carried out by periodic videographs of vehicle license plates, just as radar technology is a socially acceptable tool to apprehend speedsters. *Area licensing schemes (ALSs)* require that vehicles entering the central business district during peak hours display a monthly or daily license prominently, with enforcement being undertaken at gantry points by traffic wardens who perform visual checks on the nonstop traffic. Enforcement of ALS would be prohibitively costly when carried out at motorway speeds but would likely involve relatively low cost in a standard congested urban environment with limited gateways. ALS, also known as supplementary licensing, is found to possess the lowest cost per transaction. *Electronic road pricing (ERP) with AVI* is electronic toll

collection by time-of-day writ large and made obligatory on vehicle owners within a jurisdiction. Even though the cost of the electronic equipment for AVI is not considered trivial, the benefits are considerably higher than the cost. As the sensitivity analysis performed on the Hong Kong ERP Scheme in 1983-85 clearly demonstrates, even after excluding time savings on philosophical or other grounds, the savings in operating cost still yield benefit figures that outweigh the system cost. The much touted invasion-of-privacy issue that plagued the Hong Kong ERP scheme in the past can now be dealt with by providing road users access to confidential "numbered account arrangements" with prepaid cash deposit. The capital cost of *electronic road pricing with smart card technology* is higher than AVI alone technology, but the cost is still less than the benefits. Put together, the benefit-cost ratio and the cost per transaction can be regarded as acceptable, but this technology is still not yet widely used on a commercial basis. Nevertheless, rapid progress in microelectronics, cryptology and microwave technologies will continue to yield large-scale economies in the manufacturing of AVI equipment, read-write transponders, smart cards and the hardware and software accompaniments.

Electronic approaches of direct road use charging are shown to be superior to manual approaches whether from the perspective of a road user, road authority or society as a whole. Within these broad categories, ERP using AVI is ranked higher than ERP using smart card based on an unweighted index of all the criteria. In general, ALS is superior to cordon pricing. Hence, if budgetary conditions allow it, the feasibility of implementing ERP ought to be investigated. However, if budget is tight, then ALS (with its low cost and correspondingly high benefit-cost ratio) ought to be regarded favorably. It is argued that the most important measure (out of the twenty criteria listed) is the passage of the benefit-cost test. Nevertheless, by pursuing the multicriteria analysis introduced in the paper, the road authority could choose from amongst other criteria for deciding on the appropriate congestion charging instrument.

Finally, the disposition of the revenues collected from road pricing is crucial to its success. Based on experience as well as conceptual grounds, it appears that earmarking of the proceeds from road pricing would serve as an important prerequisite to the actual implementation of marginal cost pricing in the road sector.

Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice

1. Over 80 percent of the world's megacities are projected to be in developing countries by the year 2000. It is unlikely, however, that road capacity will be able to keep pace with the rapid growth in travel demand resulting from increases in population and vehicle ownership. Thus it is inevitable that urbanization yields traffic congestion as a by-product.¹ Some form of regulatory restraint or pricing mechanism is necessary to curtail congestion, where congestion is formally defined to be the additional cost that a motorist imposes on others.

2. This paper is the second of two papers on road pricing in theory and practice. In the previous paper, the theory of road pricing-cum-investment is reviewed and synthesized into an integrated analytical framework (Hau, 1992). Even though I deal only with charging for the congestion externality in this paper, congestion pricing would also have as a by-product the reduction of air and noise pollution from mobile sources. This market-based approach could serve as an effective deterrent to the overuse of roads by internalizing negative externalities and would thus enhance society's welfare within an urban area. Even though congestion pricing *per se* is practiced only in Singapore, road use charging in the form of electronic toll collection is rapidly flourishing in countries such as Norway, France, Italy and the United States. Charging by daylight hours in Trondheim, Norway (and further discounts for electronic tag holders during the morning peak) can be viewed as crude forms of road pricing. As part of the Intermodal Surface Transportation Efficiency Act (ISTEA) signed into law in December, 1991, the U.S. Federal Highway Administration invites state and local governments to participate in five federally-funded congestion pricing pilot programs (which include the funding of parking pricing (see U.S. Department of Transportation, 1992; Office of the Federal Register, 1992)). Further, bills to implement variants of road pricing are in the parliament of cities suffering from both pollution and congestion such as Santiago and Stockholm.

¹ For estimates of congestion costs and indices in the United States, see Hanks and Lomax (1990, 1992).

3. The first section of the paper presents a conceptual framework for congestion pricing and sets down the criteria for a 'good' road pricing system. The second and third sections review and analyze the indirect and direct methods of charging for road usage. Both sections cover a taxonomy of alternative technologies to implement congestion pricing. The several basic technologies include: 1) cordon pricing using manual tollbooths, 2) supplementary vehicle licensing, 3) off-vehicle recording systems such as automatic vehicle identification, commonly known as AVI, and 4) on-vehicle charging systems such as smart card technology. The paper introduces manual and electronic toll collection methods as precursors to the off-vehicle and on-vehicle charging instruments. The various approaches to road pricing are analyzed progressively by their level of technological advance up to the increasingly popular electronic toll collection mechanisms which exploit recent developments in automatic vehicle identification and smart card technology. The benefits, costs and revenues of implementing each charging mechanism are analyzed. Since benefit figures are not always readily available, the cost per transaction of operating a system over the long run is used as an index of the relative cost-effectiveness of each technology. Based on both quantitative and qualitative criteria, the implications of using each of these technologies for tackling congestion are summarized and conditional policy recommendations are made.

I. CONCEPTUAL FRAMEWORK

4. Urban transport is chiefly characterized by a regular pattern of peaked demands on a diurnal basis, with the highest demand occurring during the morning and afternoon peak periods. Because of the peaking characteristic of urban travel demand, in addition to pent-up demand, Parkinson's Law or Downs' Law of peak-hour expressway congestion holds (Downs, 1962; Mohring, 1965). Downs's law says that whenever new expressways are built in metropolitan areas, crowded conditions develop quickly when previously suppressed trips are regenerated and daily travelers switch to their private automobiles and desired times of travel. Worse still, when traffic density is high relative to the capacity of a facility, travelers more often than not wind up in a common gluepot in which traffic comes to a virtual standstill during the peak -- as seen in the lengthy all-day peak period of cities such as Bangkok, Hong Kong, Lagos, Santiago,

Sao Paulo and Seoul. This admittedly untenable state of affairs persists because property rights are not clearly defined. That is, even though roads are nominally owned by the government, excessive use is made of *freeways* because travelers are not appropriately excluded from using them. A road becomes 'worthless' precisely because it is free (see Vickrey's (1967) two road example)).

5. Yet there is considerable excess capacity in urban transport if one were to spread travel demand uniformly over a twenty-four hour basis -- as argued forcefully in The Urban Transportation Problem, by Meyer, Kain and Wohl (1965, pp. 83-88). Hence, it is the distinctive nature of the cyclic peak/off-peak period demands which leads to significant resource misallocation.

6. Indeed, economists have long held that road pricing could be a powerful tool in tackling congestion, improving social welfare significantly. For instance, as early as 1959 Professor William Vickrey was (and still is) championing road pricing via electronic means as a way of implementing the marginal cost pricing principle (when he testified before the Joint Committee on Washington Metropolitan problems of the U.S. Congress). It was his testimony which helped influence the distinguished members of a panel on road pricing set up by the Ministry of Transport in the United Kingdom, which culminated in the famous Smeed Report of 1964. To draw our attention, he starts out his celebrated paper (1963, p. 452) on road pricing using automatic means as follows:

"I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation. Two aspects are particularly deficient: the absence of adequate peak-off differentials and the gross underpricing of some modes relative to others. In nearly all other operations characterized by peak load problems, at least some attempt is made to differentiate between the rates charged for peak and for off-peak service. Where competition exists, this pattern is enforced by competition: resort hotels have off-season rates; theaters charge more on weekends and less for

matinees. Telephone calls are cheaper at night . . . But in transportation, such differentiation as exists is usually perverse."

Almost thirty years have elapsed since Professor Vickrey made this observation. Although some progress has been made, it is agreed by some that saturated roadways -- with almost the same level of speeds -- are still a phenomenon in cities despite massive infrastructure investments (Holden, 1989). This observation seems to square with Downs' Law.

7. Indeed, the standard way of solving congestion in the long run by increasing highway capacity via investment in the road infrastructure seems to induce ever-increasing demand for travel. Clearly, when road capacity is relatively fixed in the medium run and fiscal constraints are fully binding, the economically efficient solution is to price the use of roads differentially by setting congestion tolls which reflect the scarcity value of highway services. This is not as radical a proposal as it may seem. While some people are used to the concept of providing parking spaces themselves in garages at home, others are similarly disinclined to demand free roadside parking -- which is simply scarce road space or premium real estate -- at work places in the central business district (CBD). If parking is no longer free in busy destinations of commuters, as it once was several decades ago,² then why should people not be made aware of the high value of road space during peak hours by paying for its use? Road space is indeed one of the few examples of a good or service which market forces have left relatively unscathed.

8. Recently, the Institution of Civil Engineers (1989) and the Royal Chartered Institute of Transport (1990) came out in staunch support of road pricing as the best available instrument for utilizing a nation's existing infrastructure. They concluded that the adoption of current electronic road pricing technology via AVI is a viable means of directly charging for the use of

² In the United States, the earliest date for which (private) parking was charged for was 1917 in Detroit (Hackman and Martin, 1969).

roads in London. The United Kingdom's Department of Transport has since begun reinvestigating the feasibility of road pricing.

Criteria for a 'Good' Road Pricing System

9. In order to implement the economic principles of road pricing, a 'good' road pricing system should include a number of operational requirements listed below (Ministry of Transport, 1964, pp. 7-8; The Chartered Institute of Transport, 1990, pp. 18-20; Thompson, 1990, p. 526; and Stoelhorst and Zandbergen, 1990).³

A. From Users' Point of View (1-4)

(1) User-friendliness (Simplicity). The system should be simple to understand and convenient for motorists to use. Extremely complex and continuous pricing gradations should best be avoided because of 'bounded rationality' on the part of drivers' cognitive limitations. For safety reasons, drivers' attention ought not be diverted for more than a very short time period in the process of using the system.⁴

(2) Transparency (via *ex ante* pricing). The system should inform the motorist of the prices to be charged ahead of time and place, so that the trip decision can be rationally made and rerouted if necessary. At the time when the trip decision is undertaken, a user ought to be made aware of *when*, *where* and *how much* the charges will be. This is to be contrasted with *ex post* pricing, where users are charged only *after* the fact (as in the proposed Cambridge road pricing scheme).

(3) Anonymity (Protection from Invasion of Privacy). The system should have safeguards -- both legal and otherwise -- that are capable of assuring its citizenry of their privacy. For instance, monitoring of vehicle movements for other than strictly traffic-

³ As some of the requirements conflict, not all of them can be achieved simultaneously.

⁴ Similarly, the system should be relatively straightforward for operators to implement.

related purposes should be prohibited. This is regarded by some to be the *sine qua non* of a politically acceptable road pricing scheme. Be that as it may, currently available prepayment mechanisms using "numbered account arrangements" discussed below should prevent fears of such a 'big brother' government.

(4) Prepayment/Postpayment Option for Charging. Periodic payment should be available to the user on both a prepayment and postpayment basis. For postpayment, users can pay by standard billing procedures -- by cash in person, by check via mail, by credit card, by electronic funds transfer, etc. For prepayment, a user can set up an account by cash, for instance, and have a pre-specified sum of money transferred every time a threshold amount is reached (as is done in the Oslo Toll Ring). Ideally, such a Swiss-type "numbered account arrangement" which eliminates any paper trail should be available for those who wish to retain their privacy. If pre- and postpayment options are both offered to the user in a road pricing system, it would allow the user to choose the type of technology that suits him or her, thereby obviating the need for a potentially costly system that uniformly demands anonymity as a basis.

B. From Road Authority's Point of View (5-11)

(5) Enhanced Efficiency via Direct Charging. In order to enhance economic efficiency, the road pricing system should be able to charge directly -- as closely as possible -- the external costs arising out of *road use*. Usage of the road could be defined in terms of distance or time (as in 'closed' ticket-type toll systems). Zeroing in on usage directly would help capture and internalize congestion externalities better, in contrast to merely focusing on a proxy to usage via indirect charges. Further, normal traffic flow and speed should not be impeded artificially.

(6) Flexibility (Responsiveness to Demand). The prices charged should therefore be flexible and vary in concert, for instance, with the corresponding rise in costs caused by the increase in demand during peak periods. Sophisticated, differential pricing should vary *temporally* according to use by time-of-day, time-of-week, time-of-year, and also

spatially according to geographical location, route and possibly mode. *Per contra*, the lack of responsiveness to demand and the crudeness of the design of a given road pricing domain could lead to boundary problems both temporally and spatially. For example, traffic would be queued up just before and after certain pricing zones go into effect (as in the Singapore Area Licensing Scheme) if pricing gradations are not made continuous and fine enough.

(7) Reliability. The road pricing system should be able to operate reliably under harsh environmental conditions and should charge users correctly. However, charging a user -- or even a nonuser -- incorrectly is a much more serious error than omitting to charge. After all, a single erroneous charge could result in public relations damages that might not be salvageable (as in the case of the Gross Ile Toll Bridge, Michigan (Smoke, 1990)). On the other hand, even though a road authority may occasionally fail to charge, a vehicle which crosses a number of pricing points would still have to incur most of the charges imposed.

(8) Security and Enforcement. An ideal charging mechanism should be secure at two levels. It should be: a) free from theft of proceeds by private individuals and (toll) operators and b) free from fraud and abuse to the payment system by both individuals and operators. Whether it is deliberate or unintentional, internal or external, fraud and malfunction should be minimized to ascertain public support for the road pricing system. The system ought to be made secure: difficult for users to evade and easy for operators to spot evasion, which may necessitate the videographing of license plates in certain situations. To create deterrent effects, violators should be suitably penalized by the law for evasion and theft. To the extent possible, the burden on the regular police force ought to be minimized to maintain an acceptable level of enforcement costs.

(9) Provision for Occasional Visitors. The system should be capable of handling the infrequent visitor driving across state lines or national borders and even the regular out-of-towner. Devices for registering transactions should be made easily available for

purchase or rental from common retail outlets such as post offices, gas stations, kiosks or perhaps even automatic teller machines.

(10) 'Market' Price as an Investment Signal. The cost-based level of price simply reflects the intensity of demand and the revealed preference of travelers for certain times and locales. A high price would draw attention and mobilize resources to popular routes for investment. As such, this surrogate market mechanism serves as an indispensable guide in the planning of investment and the improvement of the services of highway links.

(11) Passage of Revenue-Cost Test. Even though revenues are transfer payments to society as a whole, the passage of the revenue-cost test could serve as an additional stipulation to the benefit-cost ratio test in the light of increasingly tight fiscal constraints and consideration of the benefit principle. However, a revenue-maximizing pricing strategy may not be consistent with a benefit-maximizing pricing one. Nevertheless, from a governmental or road authority's financial point of view, the revenue-cost ratio is perhaps more relevant if the goal of cost recovery is pursued. A positive revenue-cost ratio is a necessary condition for commercial viability.

C. From Society's Point of View (12-20)

(12) Passage of Benefit-Cost Test. Applying the standard cost-benefit test, the benefits of a road pricing scheme (in terms of the savings in travel time and operating costs, etc.) should exceed the implementation cost of such a system. That is, from a social welfare viewpoint, any road pricing instrument worthy of consideration should at least exceed a unitary benefit-cost ratio. With a limited public budget, only the most favorable projects with highest benefit-cost ratios should be implemented. The opportunity costs of raising public funds or toll revenues should be taken fully into account. Further, if benefit figures are not available, the technical efficiency of the charging mechanism could be evaluated by the cost per transaction (or charged vehicle) -- an index based on a variant of cost-effectiveness analysis applied in the long run. It should be emphasized

that cost per transaction decreases sharply with usage. In order to compare different technologies across countries, a one horse shay assumption for the capital recovery factor is used in annualizing capital cost. (The capital recovery factor of 0.125 corresponds to a discount rate of 8% and a project life of 12 years.)

(13) Minimum of Road Work and Environmental Intrusion. To ensure as little disruption as possible to an already congested road network, road work for the purpose of installing certain types of road pricing technologies should be kept to an absolute minimum (possibly using turnkey systems), especially during the day. Similarly, environmental intrusion should be minimized in an already cluttered urban environment with numerous traffic signs and stoplights, etc. Trade-offs between road work and environmental intrusion exist. For instance, microwave readers of AVI transponders could either be mounted on gantries or buried underneath the road surface.

(14) Provision for Mixed Traffic. Prices for road use should vary in accordance with the congestive effects of different classes of vehicles, be they automobiles, buses or trucks. (In order to implement marginal cost pricing of heavy vehicles properly, charging for the road damage cost and environmental pollution are called for). By using road damage charging instruments based on the monitoring of vehicle and axle loading, the ideal road pricing system is therefore able to differentiate the impact occasioned by different vehicle classes. These instruments can be implemented with modern technologies such as weigh-in-motion systems and automatic vehicle classification equipment (see, for example, Davies, 1987; Ayland, Sommerville and Tarry, 1990). Reimbursement for road pricing payments made by drivers of special categories of vehicles, disabled persons and/or residents who are granted exemptions should be made technically feasible. However, while rebates or discounts may satisfy certain public interest groups, they violate the criterion of economic efficiency.

(15) Handling of Transitional Phase. Since the installation of road pricing technologies and the minor restructuring of the transport infrastructure could not be made overnight,

the system design must include a phase-in stage. For public acceptability and softening of the system's full impact, a gradual introduction in the form of a road pricing experiment may be necessary at first (as is being done in Singapore, the Netherlands, Norway and the United States (see Office of the Federal Register, 1992)). The final road pricing system should be technologically capable of handling the vehicle population of an entire city (or even a country).

(16) Compatibility with Other Systems. For the convenience of both out-of-state motorists, domestic and foreign governmental road authorities, it is desirable that a particular road pricing system be compatible (or at least be nonintrusive or integrable without major modifications) with other road pricing systems from other jurisdictions. (To this end, current efforts to standardize both automatic vehicle identification technology as part of the *Heavy Electronic License Plate (HELP)* program in the United States and road pricing systems as part of the *Dedicated Road In-VEhicle Safety (DRIVE)* project in Europe are consistent with this criterion of compatibility). In addition, if any electronic charging system is adopted, it should conform to the radio frequency bands and safety standards set by the International Standards Organization (ISO).

(17) Modularity to Add-on Options. If a modular system is used to electronically charge for road use, public on-street parking could in principle be charged for in this way eventually. To the extent possible, and if deemed cost effective, the ultimate road pricing system should be compatible with: a) other payment schemes such as public and private off-street parking and gasoline purchases, b) automatic route guidance, c) origin-destination management information systems, and d) the control systems of commercial vehicles of private firms.

(18) Tolerance to Culture of Non-compliance. Any pricing or tolling mechanism requires a reasonably law-abiding citizenry and a culture of compliance to rules and regulations. For instance, with supplementary licensing, a good rule of thumb to test

its applicability to a particular city is to observe whether parking laws are in fact abided by generally, with double (or triple) parking regarded as a relatively uncommon occurrence. Thus a good charging mechanism should be able to have a high tolerance level of noncompliance. Yet no system is absolutely foolproof -- be it manually operated or electronically controlled.

(19) Tolerance to Varied Geography. Certain types of systems, such as cordon pricing, work well in cities with special geographical layouts. That is, a city with limited gateways (such as the island city of Bombay) may even favor a manually operated toll collection system (as in Bergen Toll Ring). Enforcement of the supplementary licensing scheme, for instance, is not amenable to traffic moving at freeway speed.

(20) Fairness and the Availability of Alternatives. It is necessary that the toll-tax incidence of the road pricing system be publicly perceived as 'fair' for it to be politically acceptable. One notion of fairness is for the government to maintain a truly revenue neutral system, where all the revenues from road pricing net of the system cost are directly or indirectly returned to the population of users (see Hau, 1992, for the conditions). Otherwise, it would be difficult for road pricing to be implemented in a democratic society. Why? This is because those who are tolled are 'forced' into paying something which used to be free and those who are priced off are 'forced' into less desirable modes, routes or times of day. Even those who had not been tolled before (those public transport captives, for instance) may be worse off as a result of riding on more crowded buses, *ceteris paribus*. Thus, almost everyone is worse off except the government. Hence, *unless* toll revenues are plowed back into the transport system in the form of: a) a reduction in first registration taxes, annual license fees, or fuel taxes, etc., b) more and better roads, and/or c) improved public transportation, it is inconceivable that congestion pricing would take off. As an illustration, good public transport and bypass routes have been provided for by the Singaporean Government to serve as viable alternatives as part of their Singapore Area Licensing Scheme, ensuring that road pricing would work reasonably well. Simultaneous with the starting date of

the Oslo Toll Ring was the opening date of a newly constructed tunnel in Oslo, which underscored to the public the government's commitment to earmark toll revenues. Thus actual and proposed road use charging schemes in Europe and elsewhere attest to the theoretical finding reported in Hau (1992).⁵ Adjustments to the current road financing instruments of first registration taxes, annual license fees and gasoline taxes should be allowed for. This is because the perceived fairness of the road charging scheme -- aside from efficiency arguments -- may require some of the toll revenues to be plowed back to motorists, public transport users and the transport system. If redistribution is found to be necessary for the political acceptance of the scheme, it is desirable that the road pricing system be technologically capable of reversing certain current vehicle charges.

II. TRAFFIC RESTRAINT MEASURES

10. Traffic restraint can be achieved via either the regulatory approach on quantity with so-called command and control measures or the market-based approach (i.e., pricing approach). Examples of the regulatory approach to roadway usage are to control the physical number of vehicles, for instance, by an "odds and evens" system and by restricting the amount and hours of parking spaces (May, 1991). The odd/even number plate system prohibits the use of private vehicles one day a week, as has been done in Mexico City since November 1989 mainly because of its air pollution problem (Carbajo, 1992). Such Draconian measures have been found to be ineffective when applied permanently (Eskeland, 1992). Aside from public transport, government and residents' vehicles, private vehicles are forbidden to enter a cordon surrounding central Milan, Italy, during the day between 7:30 a.m. and 4:30 p.m. Sometimes thought of as a cordon toll (Orski, 1992), Milan's cordon is actually a nonprice one. Other historical cities such as Florence, Rome and Bologna, Italy; Strasbourg, France; Göteborg, Sweden; and Tunis,

⁵ In Hau (1992), it is shown (diagrammatically) that road pricing hurts most people and that road users ought to be compensated, directly or indirectly, by the channeling of the toll revenues.

Tunisia have various restrictions to entry imposed on private cars -- a trend that has gained momentum in recent years (Jones and Hervik, 1992).

11. The most recent World Bank Urban Transport Policy Study paper notes that even though demand management measures such as road pricing and parking controls have been valued for some time, parking controls are the ones that have mainly been carried out in developing countries (World Bank, 1986, p. 42). While a combination of both regulatory and pricing approaches may ultimately be best suited for a particular transportation system, here we opt for the pricing approach for two reasons. First, pricing is more selective and flexible than a regulatory approach in that it provides a better market mechanism, signaling the more efficient trips to be undertaken (Pozdena, Schmidt and Martin, 1990). Second, pricing yields revenues to the community in addition to the users' savings in travel time. These revenue transfers are beneficial to society, in contrast, for instance, to society's loss of travel time due to the regulatory approach of "gating" or planned delays (May, 1986, p. 116). In particular, traffic restraint measures of banning certain vehicles in some cities mentioned above via the use of auto-free zones at certain places and times may create considerable inconvenience to individual drivers and are tantamount to setting prohibitively high prices on vehicle usage. Under road pricing, on the other hand, motorists still retain the freedom to choose the combination of mode, route and time-of-day they best prefer -- provided, of course, they pay for the privilege of doing so. It appears that administrative simplicity and political acceptability are the principal reasons why transport planners have traditionally embraced regulatory approaches.

12. Nevertheless, a cursory mention of other traffic management measures that include behavioral incentives such as staggered working hours, park-and-ride and vehicle sharing (carpooling and taxi sharing) is in order.⁶ Flextime "contains the seeds of its own destruction." This measure, once deemed successful, would reduce congestion during the peak hour, thereby creating incentives for people to switch back to their preferred times (recall Downs' Law). It seems therefore that moral suasion would not be a sustaining force in the long run. Besides

⁶ A thorough review of traffic restraint measures can be found in May (1986).

being quite costly in terms of space and construction, park-and-ride facilities built near the edge of Singapore's Restricted Zone, for instance, were one aspect of the Singapore Area Licensing Scheme that was deemed to be *unsuccessful* (Watson and Holland, 1976). Apparently, motorists found that switching modes was onerous *despite* the provision of shuttle bus services. Vehicle sharing has but a small effect on reducing congestion relative to incentives that increase the provision and use of public transport -- a form of 'bus-pooling' -- in the medium run. Cars with four or more people were considered exempt from charging in Singapore's Area Licensing Scheme prior to June 1, 1989, but are now charged when they enter the Restricted Zone during peak hours (ostensibly because authorities noted frequent pick-ups just before the zone boundary). (The same kind of abuse also occurs in some San Francisco Bay Area cities in response to the fiscal incentive that is inadvertently created when carpoolers are made exempt from tolls on bridges and tunnels or given preferential access to road capacity.) Carpooling can at best be considered a short-run strategy for combatting congestion given the inefficient use of road space. Taxi sharing, while popular for cities like Washington, D.C., is not as often used in some densely populated Asian cities such as Hong Kong since taxi fares are relatively cheap and maxi-cabs (or mini-buses) traverse along the main corridors, obviating the practice of shared ride. The regulatory control of taxi medallions is employed in many places. By restricting the supply, the quota instrument is not flexible in utilizing vehicles efficiently: those regulated vehicles on the road may not have the highest willingness to pay. In general, regulatory approaches do not prove to be very effective in managing demand in an efficient manner because of their inflexibility and bluntness.⁷ Thus, so-called traffic restraint measures that planners often aim for could be met more effectively -- albeit indirectly -- by restraints on vehicle ownership via price rather than quantity: market-based approaches are more potent than performance-based command and control measures.

⁷ For instance, a policy to restrict the parking supply in Boston, Massachusetts resulted in motorists looking around for less expensive off-street parking spaces as well as bestowing large windfall gains for the owners of private parking spots (see section on parking charges below).

III. CHARGING FOR ROADS -- INDIRECT METHODS

A. Indirect Charging via Vehicle Ownership Purchase Tax and Annual License Fees

13. Methods of charging for roadway usage can be indirect or direct (see Table 1). The most direct way of charging for road use is via electronic road use charging. The indirect methods involve charging for a surrogate of usage such as vehicle ownership. The primary instruments are acquisition/purchase taxes for vehicles, such as import duties and first registration taxes. High purchase taxes and annual license fees are often used as means of reducing the size of the vehicle fleet. They have been used quite effectively in places like Korea and Hong Kong by raising the ownership costs and dampening the rate of acquisition of private cars (Armstrong-Wright, 1986, p. 126). Hefty first registration taxes (close to 100% of the landed price) for private automobiles have been instrumental in keeping a lid on the total vehicle fleet, in contrast to low purchase taxes (around 15% of the cost-insurance-freight value) for commercial vehicles (Hau, 1989). Indeed, the resultant decrease in the aggregate number of cars means that there would be an underutilization of the road network in uncongested and rural areas, whereas the existing vehicle fleet (notably the taxi fleet) would tend to be used much more intensively in urban areas. Nevertheless, the heavy taxation via first registration taxes and annual license fees has been regarded as administratively simple and effective albeit nonselective. While high taxes on a final consumption good (such as the private car) and low taxes on an intermediate input (such as commuting) are generally considered socially desirable, high annual license fees and purchase taxes are still sledgehammer approaches to the problem of congestion because they do not address the issue of efficient road utilization.

B. Indirect Charging via Vehicle Usage

1) By Amount of Use: Fuel Tax and Tax on Tires and Vehicle Parts

14. A better method of charging for congestion indirectly is to aim for vehicle usage by the amount and the place of usage. The first instrument to consider is the ubiquitous fuel tax. Since

fuel consumption is proportional to distance, given a certain engine class, a fuel tax is perhaps the best proxy for the *amount* of usage. However, even though both stop-and-go traffic and waiting time burn up fuel under congested conditions, this method is only regarded as marginally effective (and environmentally polluting). By uniformly taxing usage independent of time and place, the fuel tax is unable to differentiate between peak and off-peak periods and usage in congested and uncongested areas. The fuel tax may on average be adequate enough as a road user charge to cover the variable road maintenance cost of a road and perhaps the environmental externalities also. Indeed, many existing systems of road user charges in the U.K. and Europe possess a combination of both high annual entry fees and a (use-related) fuel tax, which serves more or less as a very crude two-or-multi-part tariff. Other user taxes on tires and spare parts boost the operating costs of an automobile and thereby serve to reduce demand indirectly. (However, caution must be exercised -- taxes on tires or spare parts should not be so high that vehicle safety is jeopardized.)

2) By Both Amount of Use and Place: Differential Fuel Tax

15. Compared with a fuel tax, a spatially differential fuel tax with non-uniform rates would respond better to congestion. But this too, has its problems. Even though a differential fuel tax is administratively simple, it may result in wasteful "fuel-fetching" journeys, and would work only, for example, if distances between the urban and rural areas were sufficiently large. Instead of charging for vehicle use by both amount of use and place -- as a differential fuel tax does -- we can consider charging instruments related to vehicle usage by place only.

3) By Place and Time: Parking Charge

16. One of the most popular instruments which has been used to combat congestion is the parking charge on 'free' public space. The principal disadvantage of parking controls is that they lack the ability to tackle through traffic and they could actually encourage it, especially in the presence of high parking charges (footnote 7). If public on-street parking charges are set too high (and not aligned with private off-street parking rates), then congestion may result from

motorists' long searches for parking; also, additional trips may be induced in the form of the 'drive and drop' or 'kiss and ride' mode. The current widespread practice of offering motorists who patronize private car parks 'early bird discounts' before 9:30 a.m. (and charging casual motorists higher rates during the day) for instance, may not be early enough to mitigate those commuters' congestive effects. For parking charges to tackle congestion effectively, they should be time-of-day and/or location-dependent charges rather than present market-determined parking rates with locational monopoly element. Ideally, farther parking spaces are priced lower and closer ones are priced higher, with the result that early and late arrivals would select themselves in an efficient manner which minimizes the time that it takes people to arrive to work behind schedule (see Arnott, de Palma and Lindsey, 1991, for proof).⁸ Some cities such as Washington D.C. and San Francisco even institute parking taxes. Only if municipalities control a large fraction of both on-street and off-street car parks would the parking tax be an effective instrument at combatting congestion (Department of the Environment, 1976). In general, increases in the parking tax would not be as powerful an instrument in combatting congestion and pollution as direct charges would (Kulash, 1974).

17. Nevertheless, parking charges within the Restricted Zone of the Singapore Area Licensing Scheme (see below and Annex 1) were raised substantially above market rates, in addition to a surcharge, as a matching tool to road pricing. In the absence of road pricing, a parking tax is sometimes regarded as a surrogate to charging for the use of congested urban streets (see Burns, 1972; Churchill, 1972, p. 15). While a parking tax may or may not be desirable, parking pricing as well as controls ought to be pursued since driving and parking are jointly demanded (Churchill, 1972, p. 15). After all, not charging the full cost would constitute subsidies (see World Bank's Transportation Sector Working Paper, 1972, p.23; World Bank's Sector Policy Paper in Urban Transport, 1975, pp. 9, 15 and 42; and World Bank's Policy Paper on Urban Transport, 1986, pp. 91-92). Empirical case studies of employer-subsidized

⁸ A social optimum is reached only by combining time-of-day road pricing with a location-dependent parking fee (conditional on parking inward) (Arnott, de Palma and Lindsey, 1991). Further, to signal commercial traffic and shoppers appropriately, time-of-day and length-of-stay parking charges should be used (see World Bank, 1986, p. 11).

parking show that parking subsidies induce solo driving, decrease carpooling and public transport use (Willson and Shoup, 1990; Shoup and Willson, 1992). As a consequence, people suffer from worsening traffic congestion, increasing fuel consumption as well as air and noise pollution.

4) By Place and Time: Supplementary Licensing

18. The most important instrument of charging for road use by place of usage is with supplementary vehicle licensing, also known as area licensing. In principle, supplementary licensing requires that traffic moving within the designated area be subject to enforcement but in practice this concept has never been carried out.⁹ Hence this system is essentially an admissions charge to certain congested areas (such as the central business district) during certain (peak) hours, and is really a form of cordon pricing. Instead of stopping at a toll gate to pay for the entry manually -- and creating queues in the process -- as in the conventional notion of cordon pricing, motorists are required to prepurchase a sticker. Either a daily license or a monthly license is obtained at sales outlets such as post offices and so on, and the sticker is then placed in a visible area behind the windshield. If only one (or two) restricted zone is mandated, enforcement is relatively straightforwardly carried out by having traffic wardens standing by the side of the city street and marking down the license plates of those offending vehicles and mailing them a ticket afterwards. (In general, two or three traffic wardens are required to handle one station or gantry, as has been the practice for about 17 years in Singapore.) For ease of enforcement, stickers vary by shape and color to differentiate the days on which they are to be used. It is possible to vary charges by more than one time period or zone by a combination of two different stickers but, in principle, more complex time-of-day pricing schemes would

⁹ In fact, the charging of the presence of vehicles within a cordon was proposed for London (Greater London Council, 1974). It was argued that the enforcement or personnel costs would be less if enforcement were carried out inside rather than at the numerous entry points. This variant is not as focused since vehicles which arrived before dawn, contributing nothing to congestion, would nonetheless be charged. Strictly speaking, supplementary licensing, without the enforcement of vehicles which have been left or garaged within the designated area overnight, say, amounts to direct charging for entry to a cordon via manual tollgates, to be discussed later.

involve problems of enforcement which may be difficult to manage even at city traffic speeds. Thus a distinguishing characteristic of supplementary licensing vis-a-vis cordon pricing using manual tollbooths is that it is relatively easier to implement more complex pricing schemes within two or three concentric zones by using multiple stickers and increasing modestly the enforcement personnel under area licensing than with manual tollgates.

19. The superiority of supplementary licensing as an instrument over the parking charge or tax is that it is able to price for the passage of through traffic nonstop. However, supplementary licensing suffers in reality from abrupt changes inside or outside of a designated zone boundary and also from changes just within or outside a time period, whereas the parking charge could be set to taper off towards both the city edge and the end of the rush hour. Another disadvantage is that a vehicle, having paid the entrance charge, would have the incentive of contributing to circular traffic within the zone since the leg of the trip therein is not charged, possibly exacerbating congestion. (As a variant, this problem could potentially be overcome if enforcement of area licenses was carried out for vehicles' presence within the zone, that is, on both moving and stationary vehicles (see previous footnote).) These are what I regard as the *spatial* and *temporal* boundary problems of supplementary licensing. One way of circumventing the boundary problems is to be flexible in its administration, for example, by expanding or narrowing the physical boundaries after a certain period and extending the time period(s) in which charging is in effect (as has been carried out in Singapore). A supplementary licensing scheme is very cheap to implement, requiring little capital outlay except for setting up gantries. To be cost-effective, supplementary licensing -- like cordon pricing -- requires that the number of entry and exit points be kept to a manageable figure. Area licensing schemes are especially suitable in labor-intensive developing economies and places that have a good track record of compliance with well-enforced traffic laws. Because operating costs involve only printing costs, the hiring of traffic wardens, and electricity, it is especially amenable to a short-term demonstration or field trial to test its feasibility in a small but congested city given its reversible and flexible nature. Other potentially minor problems such as theft and counterfeiting of daily and monthly licenses can presumably be dealt with by passing new legislation and imposing penalties that have deterrent effects. Supplementary licensing is exemplified by the only road

pricing scheme in existence, albeit crudely, Singapore's Area Licensing Scheme (ALS), in operation since June 1975 (see Annex 1). Just prior to June 1, 1989, drivers of automobiles entering the Restricted Zone were required to display prepurchased stickers of about S\$5 [US\$2.84 using 1990 exchange rate] in the morning peak. Thereafter, the daily license fee became S\$3 [US\$1.65 in 1990 dollars] during both the morning and afternoon peaks.

IV. CHARGING FOR ROADS -- DIRECT METHODS

20. Having considered the major indirect instruments of charging for congestion, we turn now to direct methods of charging for the use of roads. Direct charging could be broadly categorized as off-vehicle recording versus on-vehicle metering. With off-vehicle recording, as with telephone, gas and electricity charges, the actual charging is monitored off the vehicle even though a transponder may be placed on the vehicle itself in the case of automatic scanning. On the other hand, with on-vehicle metering, actual charges are registered on the vehicle itself using automatic meters -- similar to the concept of taxi meters and (stored value) phone cards. All of the off-vehicle recording methods are based on point pricing whereas on-vehicle metering methods involve either point pricing or continuous pricing. Point pricing refers to the pricing of a vehicle when it passes a charging point such as a toll site. Continuous pricing, on the other hand, involves clocking a vehicle for the time spent or distance covered between two charging points.

A. Off-Vehicle Recording

21. Within the off-vehicle recording category are three instruments: 1) manual charging by admissions fee via tollgates and reserved lanes; 2) automatic scanning via automatic vehicle identification (AVI) technology, otherwise known as electronic toll collection (ETC) or euphemistically called electronic toll and traffic management (ETTM); and 3) a combination of manual and automatic scanning of vehicles. Manual and/or electronic toll collection involve point pricing and hence are less costly to operate than continuous pricing methods.

1) Manual Charging via Tollgates

22. The first mechanism to consider is the use of manual tollgates. This is an established and well-known technology, administratively straightforward, publicly accepted for toll roads, bridges and tunnels, as well as politically palatable. However, manual charging results in low throughput, with about 350-400 vehicles per hour for a toll lane (Hartje, 1991; Ardekani, 1991). In contrast to supplementary licensing, in which systems costs are relatively low and user costs are also low because of its nonstop nature, the setting up of tollgates requires significant capital investments in toll plazas and toll collection facilities. In order to cater to the typical need for two to three approaching toll lanes to conservatively serve every expressway lane (as in the United States (Seila and Wilson, 1991)), toll plazas require large plots of open space, not often found in urban areas.¹⁰ The construction cost of toll lanes (and tollbooths) and land acquisition costs are all fairly high in major conurbations. The operating cost is nontrivial because it is heavily driven by toll operators' salaries. Based on a sample of six mainline/ramp barrier systems, the toll collection cost per transaction ranges from US\$3.6 cents to US\$7.5 cents in 1983 (Wustefeld, 1988, Table 5).¹¹

23. The tollgate method of direct charging is akin to supplementary licensing if one is considering a simple zone, and is therefore able to tackle the problem of through traffic not captured by the instrument of parking charges, for instance. However, manual charging imposes more externalities than it attempts to internalize by requiring that all vehicles come to a full stop to elicit payment, creating long queues and waiting times inevitably. The stop-and-go traffic results in increased travel time and operating costs (in the form of fuel and vehicle wear and tear). Besides being particularly susceptible to these costs, heavy vehicles also create severe road damages as a result of stopping and starting. In general, less attention has been paid to the

¹⁰ Small wonder the Smeed Report (Ministry of Transport, 1964) dismisses this approach to curtail congestion in a mere couple of sentences.

¹¹ These figures are based on toll facilities which have lanes for both manual operation and automatic coin machines.

increased risk of accidents and pollution levels at toll plazas. Other problems have been encountered, such as the lack of financial control of toll box revenues. Scandals periodically arise in which toll operators embezzle cash cages. The need to physically transfer large amounts of coins is another problem.

24. Besides the manual operation of tollbooths, automatic coin machines and hoppers for exact change are also used to save on personnel costs; automatic coin machines marginally improve the throughput to about 400 vehicles per hour for a toll lane. The disadvantage of these machines is that they still require vehicles to come to a stop. Note that six approach toll lanes are required to serve one expressway lane in order to ensure that the capacity of the road itself is not constricted by the capacity of the tollbooths.¹² This suggests that tollbooths could be designed in a way that does not disrupt traffic, but manual charging would involve unacceptably high set-up and operating costs relative to other mechanisms. One minor disadvantage of using automatic coin machines is that charging for one type of vehicle is only applicable on a per lane basis, unless different vehicle types are designated to use specific toll lanes, which would decrease the capacity of the toll booths and increase the complexity of the charging instrument.

25. Another form of charging is with the use of coupon books. They have similar advantages to automatic coin machines but the printing cost is not insignificant. Similarly, problems of fraud occur. (The magnetic card method of running magnetically-striped cards, such as credit cards, through a mechanical reader may help control operator fraud, but would be the slowest and least practical method of all.) Based on a sample of five ticket system toll roads, the cost per transaction ranges from US18.4 cents to US42.4 cents in 1986 (Wustefeld, 1988, Table 6).

26. Perhaps the irony of using the tollgate approach to tackling congestion can be expressed as follows: if an urban area is congested, then the planner ought not add to the congestion externality the non-negligible cost of transaction itself. At the other extreme, if the facility is

¹² I am indebted to Richard Scurfield for clarifying these points.

uncongested, then the planner should not impose a charge since the incremental congestion cost is nil.

27. From a financial point of view, if the system is installed for a long period of time, the large capital costs of toll plazas could also be amortized over more years. Thus, from an operator's perspective, this system is more amenable for a long-term demonstration or experiment rather than a short-term one (Bhatt, 1974). If so, the long-run cost per transaction is a valid index for analyzing the cost-effectiveness of alternative charging instruments -- assuming that the aim is to curtail one (socially wasteful) trip.

28. It would be a relatively simple matter to implement cordon pricing using manual tollbooths with just one single zone. However, urban areas seldom have the necessary space for two (or more) suitably designed cordons manned with tollbooths to implement multi-zonal, cordon-based pricing. As such, this method is inferior to the ALS method of cordon pricing because it impedes traffic. Like the ALS, since charging on a continuous basis (by time or distance) is impractical, the charging basis is done via point pricing, i.e., by crossing a gantry point. Unless pricing gradations are fine enough (which as we have discussed is infeasible with the tollgate collection mechanism), boundary problems would arise with vehicles slowing down or even parking outside a zone boundary just prior to a change in the period of operation, similar to problems with ALS. Once inside the zone, however, there is an incentive for additional mileage to be undertaken, adding to congestion. The prime example of cordon pricing which utilizes manual tollgates is that of the Bergen Toll Ring, in operation since January 1986 (see Annex 2).

29. Under what circumstances are tollbooths acceptable as an instrument of charging for congestion? Only if: i) the number of entry and exit points is limited, and ii) the capacity of the road is not greatly constrained by the capacity of the toll collection facility itself. When equipped with a minimal number of toll lanes to reduce transactions delay, the few entry points to the urban area could also result in tolerable capital and operating costs. With this method, it is desirable to establish reserved lanes for those with seasonal passes (as was done in Bergen)

to maintain nonstop traffic through the tollgates as well as to limit personnel costs. As traffic growth increases along trend and the net benefits of curtailing congestion rise, the setup of the reserved lanes is ideally suited for the conversion to electronic subscriber ones (which charge on a *per trip* basis), as is done in Oslo following a trial period of using seasonal passes.

2) Automatic Scanning via Automatic Vehicle Identification

30. The second mechanism of directly charging for congestion on an off-vehicle recording basis is automatic scanning via automatic vehicle identification (AVI). As with manual charging, this is considered point pricing as vehicles are charged when they pass a reader known as an interrogator. The third mechanism under the rubric of charging for congestion by direct methods by registering charges off the vehicles is simply a combination of manual and automatic charging. Since the basic technology for automatic road use charging has been tested and used on toll roads, tunnels and bridges, I shall first discuss the pros and cons of electronic toll collection (ETC) using AVI in such open environments and then discuss its application and extension to road pricing within a city-wide context.

AVI Technology

31. Automatic vehicle identification (AVI) refers to the automatic identification of vehicles in motion. The term 'automatic vehicle identification' is a bit of a misnomer since it is the transponder located in the vehicle rather than the vehicle itself that is 'identified' (Thomson, 1990). Thus the less evocative term of 'electronic toll and traffic management (ETTM)' is the one currently adopted and popularized. Historically, AVI was first developed and tested in the 1950s and the early 1960s (Vickrey, 1959; Ministry of Transport, 1964; Catling, 1987). The Port Authority of New York and New Jersey supported the development of AVI technology as early as 1963 (Foote, 1981). In fact, it was upon the instigation of the American Association of Railroads that AVI technology was originally pioneered in the early 1960s for the purpose of tracking railroad boxcars. AVI technology is now widely used in rail transportation and intermodal transportation.

32. Schematically, AVI consists of three functional elements: a transponder (known as a 'tag') which stores a unique identification code; an interrogator which 'reads' a transponder and decodes its identification; and a computer system which transmits, analyzes and stores data (Davies, 1989; Sommerville, 1991). There are four broad types of AVI technology:

- Optical and infra-red systems
- Inductive loop systems
- Radio frequency and microwave systems (including surface acoustic wave technology)
- Smart card systems

33. One of the earliest generations of AVI technology involves optical means (Davies, 1989; Sommerville, 1991).¹³ It is not unlike bar code scanning available in grocery store checkstands (which are not close to being considered fully reliable). With optical systems, the coded labels are placed outside the vehicle. A laser beam from an optical scanner tracks the bar code sticker placed on side windows and analyzes the reflected light. However, this technology becomes less reliable under conditions of poor visibility (e.g., when there is dirt, snow, ice, rain or fog). Further, counterfeiting of bar codes is easily carried out and a vehicle's speed is lowered when attempting to meet the exacting requirements imposed by optical systems. Computer scanning of vehicle number plates have been tried on some French toll roads but still has not reached a tolerably low error rate in readability. In the 1970s, infra-red technology based on similar principles of operation as the optical-based ones also floundered when subjected to poor environmental conditions.¹⁴

¹³ Optical-based automatic car identification (ACI) is still used in some nonroad-based transportation environments, as exemplified by the Washington Metro's use of ACI since 1976 (Armstrong, 1984).

¹⁴ Automatic or electronic route guidance, which does not require very stringent requirements of reliability, currently uses a more advanced infra-red technology based on a dynamic two-way communications between an in-vehicle unit and a roadside beacon. Static route guidance uses self-contained, mapping information stored in a vehicle only, whereas dynamic route guidance obtains digital map information and routing recommendations both aurally and visually. The latter manages traffic flow by using road-side infra-red beacons to transmit and receive dynamic data to all moving vehicles in (almost) real time (Catling, 1990). Siemens' Euro-scout system -- the latest generation of the ali-scout system -- has been in full scale field trial

34. A second type of AVI technology is the inductive loop system, which operates like a conventional traffic detection and counting loop mechanism embedded in the road pavement (Davies, 1987; Catling, 1987). Since an inductive loop system operates at frequencies between 50 and 500 KHz, it can also be regarded as a low radio frequency system. Operationally, an antenna loop situated in the pavement communicates with a transponder mounted underneath a moving vehicle. Basically, there are three types of systems: active, semi-active and passive. The active system derives its power from the motor vehicle's power supply itself. Since the electronic transponders are powered externally in an active system, the security of the system may be vulnerable to external interference inadvertently. A passive transponder is one which is energized when the vehicle passes a power loop buried beneath the road surface. In response to being activated, the transponder's identification code is decoded and returned to receiver loops embedded in the road, which in turn transmits the information to a computer for data processing. Tests carried out by California's Department of Transportation confirm the known fact that the performance of inductive loop systems is adversely affected by steel-reinforced pavements (Davies, 1989). While free of the aforementioned shortcomings of an active system, a passive transponder's principal disadvantage is the limited field length within which it could be triggered and operated.¹⁵ Thus, a more recent technological development which aimed at overcoming

in Berlin for at least four years. GEC's Autoguide system has been tested on an experimental basis since early 1988 in London and a commercial system is expected to be available in 1993 (Catling, Harris and McQueen, 1991; Belcher and Catling, 1987). The United Kingdom's Transport and Road Research Laboratory (TRRL) estimates that Autoguide users could achieve average travel time savings of around 10% and a reduction of distance driven of 6% (Department of Transport, 1988). On the other hand, because traffic is already around capacity level during peak periods, a slight decrease in traffic, as a result of diverted traffic, results in significant savings of £125 million per year for London (assuming only 400,000 users out of 3 million registered vehicles subscribe to Autoguide). The cost of the *pilot* stage ranges from £5 - £10 million in 1988 figures. It is also estimated that the benefits of a dynamic route guidance system are substantial at about £800 million per year in the UK alone and over £4000 million per year for Europe (Jeffrey, 1986). The economic benefits are broken down as savings in direct fuel cost (15%), savings in operating costs (40%) and savings in travel time (45%). In the United States, the Federal Highway Administration is comparing the benefits of different route guidance schemes such as Pathfinder as part of the Intelligent Vehicle Highway Systems (IVHS). It is recommended that automatic road user charging systems be designed to be compatible with route guidance systems in future *Dedicated Road* and *In-Vehicle Safety* (DRIVE) projects in Europe (Catling, 1990).

¹⁵ A prime example of an inductive loop system is the AVI system which was thoroughly tested for the Hong Kong Electronic Road Pricing Scheme. It uses a transponder of the passive type – known as an electronic number plate (ENP) – which contains standard and proprietary integrated circuits and several ferrite aeri-als

the shortcomings of both systems involves the production of a semi-active transponder with an internal lithium battery which yields greater operating distance as well as relatively long life. Active inductive loop systems have been used for automatic bus identification in the United States, Europe and Australia (Catling, 1987).

35. Radio frequency (RF) transmission (otherwise known as high RF or microwave technology) forms the third and presently most popular type of AVI technology. The system is modular and the radio frequency transmissions span the officially-approved KHz, MHz and GHz ranges. Because of the higher frequency, more data can be packed and transmitted back and forth via RF technology, which is vital to enhancing system security. At the same time, lower operating wavelengths of microwave systems result in the manufacturing of a smaller and lightweight transponder that can be easily slipped into someone's shirt pocket and thus made transferable from vehicle to vehicle without any difficulty. Just as with inductive loop systems, there are three types of transponders with microwave systems, namely active, semi-active and passive transponders, and the same qualifications apply to them. Further, with microwave technology, a high frequency level is needed for use with a nonbattery powered tag, which could potentially pose a health hazard, at least psychologically.¹⁶ Thus a semi-active tag appears to possess the advantages of being able to transmit large amounts of information in a very short

for receiving and transmitting signals. Developed by Plessey Controls Ltd., the ENP is about the size of video-cassette tape, weighs 1.2 kg [2.6 lb], and would be permanently installed on a vehicle's underside, fully deserving the designation of 'automatic vehicle identification'.

¹⁶ An example of radio frequency AVI technology is US-based Amtech Systems Corp.'s TollTag®. Amtech's passive tag (priced at US\$32.25 a tag in 1992) involves one-way communication, weighs 40 gm [1.4 oz] and operates at the reserved frequency of 915 MHz (with a range from 850 to 950 MHz) and possesses a maximum field length of 9 meters [30 ft]. A heavy duty Amtech transportation tag weighs four times more and operates at 915 MHz as well as 2.45 GHz (with a range from 2.4 to 2.5 GHz) -- the frequency at which the industry aims to standardize at. The three major frequency bands used are 880 MHz, 915 MHz and 2450 MHz.

In Spring 1992, Amtech came up with the IntelliTag™, which uses the same "modulated backscatter" reflective technology. Priced at around US\$40 a tag in large quantities or US\$49.50 a tag, the two-way communication link provides for 240 bits of fixed and variable data storage space (such as time and date stamp, account balance, etc.) on the transponder. These features allow for read-write transactions that are fully capable of protecting privacy.

time and over a relatively longer operating distance. In addition, a semi-active tag can keep the power transmission level of microwave antenna-readers at tolerably low levels.

36. Surface acoustic wave (SAW) technology is yet another recently developed radio frequency-based AVI system (Sommerville, 1991).¹⁷ Application of the RF technology is widely used on those toll roads in the United States which utilize AVI technology, whereas SAW technology is used on toll roads equipped with AVI in Norway. For the most part, microwave technology appears to have superseded AVI technology based on optical and infra-red means. It involves no action on the part of the motorist: he or she simply buys or leases an electronic tag and places it behind the windscreen or the rearview mirror using attachments such as velcro pads, letting the electronics automatically charge for toll crossings. Since many of the transponders operational on toll roads are of the passive and read-only type, they are (thick) credit card-sized and they are removable. Such a transponder electronically communicates its encrypted identification code with roadside readers via high frequency radio waves.¹⁸

37. How does the system work? A vehicle is driven past a pricing point nonstop at high speeds (up to a maximum speed of 300 kph [180 mph] in principle). An antenna -- connected to a reader -- is placed by a signpost (or mounted above on a gantry) and broadcasts a radio frequency towards a transponder placed inside the speeding car. The AVI tag 'modulates' the radio frequency which it receives and reflects its encrypted identification code back to the antenna, which is then relayed back to the reader. The reader's function is to interpret the identification code from the signal, decrypt it and validate the code according to predefined criteria. If the security check verifies that a transponder is valid and a motorist's account is fine, an indicator light by the roadside would turn green. A yellow light may indicate that a

¹⁷ An example of an AVI system with SAW technology is Norwegian-based Micro Design's Queuefree-Tag. Micro Design's passive tag (priced around NOK100 in 1990 [US\$16]) weighs about 31 gm [1.1 oz] and operates at the reserved frequency of 856 MHz.

¹⁸ A passive tag (like the one from Amtech or Micro Design) is beam powered and has an almost indefinite service life because it contains no movable mechanical parts. A (semi-)active tag is battery powered and has a service life of about ten years -- which is likely to exceed the life of a vehicle or be overtaken by obsolescence.

user's account is low and a red light would indicate that a defective or fraudulent tag is used, at which time the video enforcement system automatically takes a picture of the offending vehicle. (In principle, even though a traffic cop could be dispatched immediately to apprehend violators, in practice they are merely sent tickets in the mail as with speeding violators.) The reader then transmits the data to a central computer system -- composed of a system of commonly used microcomputers and a minicomputer -- which records information such as the identification code, the location, date, time or the vehicle class code and performs off-vehicle charging either by prepayment or postpayment. A motorist can choose to pay in advance or in arrears. For prepayment, a user's account is linked to a bank account and a pre-specified sum is deducted periodically (alongside the toll rate itself) via electronic funds transfer (giro payments) or credit card payment. As is currently done at toll facilities in Europe and the United States, prepayment could also be performed without a bank account by placing a prepaid cash deposit in advance, as with a numbered account arrangement (thus protecting the individual's privacy). For postpayment, conventional monthly or quarterly billing statements can be automatically sent out and straightforwardly processed. Even with automatic *vehicle identification*, the optional nature and wide variety of payment options would therefore not pose a threat to citizen's civil liberties.

38. Smart card-based systems form the latest state-of-the-art technology in AVI (Thompson, 1990).¹⁹ Smart card technology is based on a two-way communication link between a 'smart' on-board unit and a roadside antenna. An on-board unit is composed of a smart card, a smart card reader and a transponder.²⁰ In addition to the standard integrated circuits found in radio

¹⁹ As a precursor of the chip card, the plastic magnetic stripe card (as exemplified by the credit card and bank card) is ubiquitous and very cheap to manufacture -- less than a dollar each. The magnetic stripe card suffers from: 1) the defect of being easily copied; 2) low memory capacity; and 3) the requirement for it to be used together with a mechanical, motor driven reader that is unreliable.

²⁰ The Telepass system is the only smart card system in operation since May 1990 on Italy's Autostrada. In the Italian system, the transponder -- located in the on-board unit itself -- is responsible for transmission and reception of roadside to vehicle information and operates at 5.72 GHz. Hence it is over six times faster than an RF technology which operates at 915 MHz, allowing for added measures of encryption and security. In addition to being a supplier to Telepass, AT&T has recently teamed up with Vapor Canada, Inc. to integrate its 'contactless' smart card used in banking applications (which has the capacity to store four pages

frequency tags, the smart transponder possesses a microprocessor which has both read and write capability -- functioning much like a simple miniature computer. Hence, the smart transponder is able to maintain a transactions balance independent of a central computer and can perform simple arithmetic operations when activated, acquiring the function of an electronic purse -- similar to a phone card or a stored value card available on metro systems.²¹ Whenever a vehicle passes a charging point, the on-board unit can be programmed to emit a bleep or a tone to signal the completion of a valid transaction (Dutch Ministry of Transport and Public Works, 1989). The smart card can be revalued at designated machines located at certain fuel stations after the decrements reach a threshold level, whereupon a warning yellow light emitting diode (LED) on the in-vehicle unit to which the card is attached is automatically turned on. (This is the modern hands-off version of operating a mechanical on-vehicle meter by hand as envisioned in the Smeed Report, so I call its electronic equivalent 'on-vehicle metering'.) Other functions include the capability of monitoring -- with the use of designated machines -- a previous history of the record of the transactions made (up to 200, say), possibly for the purpose of contesting any alleged discrepancies. The prime advantage of smart card-type AVI technology relative to microwave AVI alone technology is that there is no paper trail, and that anonymity/privacy is assured. A second advantage of smart card system is that it obviates the need to maintain a costly central charging system capable of handling all the separate user accounts. The latter feature is a requirement -- and shortcoming -- of one-way AVI systems. A third advantage is that a charge that is deducted instantaneously would presumably have a greater impact by making

of information) with electronic toll collection (Skrzycki, 1991). (A 'contactless' card means that it involves no metal-to-metal contact or movable mechanisms when it is read by an in-vehicle smart card reader.) AT&T's transponder is said to be priced around \$100 with smart card attachment (Ramirez, 1992).

The PAMELA project, developed as part of the Cambridge road pricing scheme, envisions at least two versions of smart card technology: one which contains all the microwave communications circuits in a single credit-card sized unit and another which splits the on-board unit into a small card reader which contains the circuits and a separate smart card which acts only as a value card (Hills and Blythe, 1991). Here we consider the latter, more basic version.

²¹ In computer jargon, a phone card is a chip card without intelligence and is of the read-only memory (ROM) type. On the other hand, a smart card (as used on a large scale in several banking applications in France) is a chip card with both a microprocessor and a memory, of the electrically erasable, programmable and read-only memory (EEPROM) type.

the driver more keenly aware of a trip's cost (especially via an audio beeper and a LCD visual display of the account balance) -- and thus modifying his travel behavior -- than a billing arrangement settled by credit card at the end of the month. The disadvantages include the fact that the theft of an electronic purse becomes a potential problem precisely because of its nontraceability -- whereas if a radio frequency-based AVI tag is stolen, it becomes worthless once it has been reported lost (as with a credit card). Hence the major strength of the smart card system is also its vulnerable point. This problem could be partially addressed if the maximum denomination of the smart card's account balance is limited and the penalty high. It has also been suggested that a smart card could be keyed in (with a PIN number) by the user to operate in tandem with the owner's in-vehicle unit, but the entire unit would still be a potential target of theft. The other chief disadvantages of smart cards are that they require complex vehicle to roadside communications and that multi-lane problems still need to be overcome entirely, as compared with microwave AVI systems which are less vulnerable to those problems. Sophisticated vehicle to roadside communications could be used as an opportunity to integrate electronic route guidance and information systems with the smart card automatic debiting system. The use of smart cards for AVI, despite their higher cost vis-a-vis microwave AVI, may be integrated with the growing use of smart cards in several banking systems in France and Japan, making them more appealing in the future.

39. As an intermediate step to a full smart card system, a simpler memory tag which has some read and write capability can be used (see footnote 16). One such system has been tested experimentally since November 1987 at a tunnel in Ålesund, Norway. It operates on similar frequency and transmission speeds as the above-mentioned smart card system and allows vehicles to travel up to 60 kph [37.5 mph] by the tollgates.²² However, it does not have as much flexibility as, or the varied uses of, a standard commercial smart card with banking applications.

²² Based on microwave technology, this intermediate system is called the *Programmable REMote IDentification* (PREMID) system. Using a match-box sized, semi-active tag powered by a long-life lithium battery, it operates at 2.45 GHz -- still a relatively fast transmission rate -- and up to a distance of 5 meters [16 ft] (Philips, 1988). The PREMID tag can handle up to 32 Kbytes of memory. A more advanced PREMID transponder by Sweden's Saab Combitech Traffic Systems with read-write capability was tested beginning Spring 1992 at the Eastern Harbour Tunnel in Hong Kong.

More recently, in August 1992, the Illinois State Toll Highway Authority adopted a 'smart' transponder system for its Illinois Tollway.²³ This technology has features of a smart card system such as read-write capability performed at freeway speed. It is equipped with a LCD visual display for checking toll and parking account balances as well as an audio system that is capable of warning drivers that electronic toll collection or accidents are to be expected a mile ahead. This allows ample time for the motorist to avert bottlenecks.

40. The advantages of electronic toll collection vis-a-vis manual toll collection are many. Vehicles do not have to slow down, form queues and create congestion because of the transactions cost of manual toll collection. Vehicles can travel at the desired speed (well beyond the current speed limits), with instantaneous debiting of accounts being undertaken at reliability and accuracy levels exceeding 99.9%.²⁴ Nonstop traffic results in smooth traffic flow and high throughput of 1200 to 2000 vehicles per lane-hour -- triple to more than quintuple the throughput of a conventional manual toll lane. Further, no stopping and paying means decreased fuel consumption, lowered risk of accidents, pollution and road deterioration (especially the road damage caused by heavy vehicles' alternate braking, stopping and starting action). Gone are huge toll plazas with large plots of land and in their places are gantries (or nothing, if in-pavement antennas are used). In some AVI systems, the motorist is instantaneously notified by a green light (indicating a valid account), a yellow light (indicating a low account), or a flashing red light (indicating a depleted account or a malfunctioning tag). State-of-the-art technology does not need major road work, as was required for the outdated Hong Kong electronic road pricing technology in 1983-85; it requires, at most, that a small slit be cut on the pavement to embed a thin electronic loop, and that this be covered over with sealant. With in-pavement

²³ In the winning bid, AT/Comm Inc.'s cigarette-pack-sized, microprocessor-based transponder is priced at US\$37 each -- about 35% less expensive than competing smart card transponders. This read-write tag (containing 16,000 bytes of data) has the twin advantage that it avoids the need to maintain a costly central computer system required of one-way AVI systems and is capable of fully protecting motorists' privacy while they are traveling at expressway speeds. The AT/Comm tag can store up to 24 separate accounts, potentially overcoming the problem of different toll authorities and jurisdictions sharing the proceeds of the same account.

²⁴ Figures are based on tag-based AVI systems as reported in company brochures (from Amtech System Corporation and Micro Design; see following footnote).

antennas installed in such a discreet fashion, the road surface appears to have crack seals on it and is unobtrusive compared to gantry-mounted antennas. In short, great strides have been made in AVI technology, which draws us much closer to feasible electronic road pricing in a city-wide context.

Examples of AVI systems

41. A simple turnkey AVI system began daily operation at the Crescent City Connection Bridge, New Orleans, United States, in January 1989. Since it was a retrofitted AVI system on existing tollbooths, the system was installed for slightly less than a million US dollars. The operating cost is merely a maintenance contract with the AVI supplier -- Amtech -- and four sales clerks and a fraction of a technician's time, which comes to over US\$100,000 a year. With about 30% AVI users for an average daily traffic count of 60,000, the cost per (AVI) transaction comes to less than 4US cents at 1990 prices. Due to low capital cost of US\$1 million, the cost per dollar of toll financing is only around 1%.²⁵

42. The second set of figures presented here is based on the information proposed in 1990 for the Dulles Toll Road, Virginia, which connects the Dulles Airport to Washington, D.C. Their much delayed so-called Fastoll system is a fully integrated toll and AVI system, which includes enforcement cameras, fiber optics, communications, barriers, variable message signs and conventional toll equipment, etc. This accounts for the fact that the system is estimated to average US\$16.5 million in capital cost and US\$5 million in operating cost in 1990.²⁶

²⁵ Usage of the current Amtech technology by the toll authority of the Louisiana Department of Transportation and Development indicates a "99.9% reliability" level (thus appearing to verify manufacturers' claims) and a very cost-efficient operation (since use of AVI reduces personnel costs three times). A drawback of the system in use in 1989-90 is that enforcement was carried out (without an add-on video recording system) by requiring that all vehicles slow down (and perhaps come to a stop) at the tollbooth until the electronic security system verifies the validity of the transponders before lifting the automatic barriers. This is done despite the fact that the technology is fully capable of handling speeds well beyond the speed limit. Motorists in New Orleans place a US\$25 deposit for the use of an Amtech TollTag®.

²⁶ The Virginia Department of Transportation opted for an out-of-sight transponder to be externally mounted underneath the vehicle and scanned by in-ground antennae (see DeLozier, 1990).

43. With an average daily traffic count of over 70,000 and the total number of transactions of 250,000 (due to a car passing multiple toll points), the cost per transaction comes to an average of *US\$7.7* cents in 1990. Because of the relatively high capital cost of the system (including conventional toll equipment), the revenue-cost ratio is only about 1.6. Even so, the advantages of having such a sophisticated system of electronic toll collection is the indirect savings of not building, equipping and staffing approximately 100 additional toll lanes. After all, highway construction cost is in the range of *US\$1.25* million per kilometer in 1990. (An attended (manual) toll lane costs *US\$176,000* a year -- 11 times more costly than an AVI ('Pikepass') lane of *US\$15,800* a year, reports the Oklahoma Turnpike Authority.) Dedicated telecommunications links, although not required, were chosen to improve security. As of this writing, the system has gone through two rounds of bid proposals and should be in operation soon.

44. In the two case studies, one actual and the other proposed, the issue of privacy is not important because travelers can voluntarily participate in electronic or manual toll collection. The issue of road work is also not crucial because a minimum of it is needed. Besides Crescent City Connection and the Dulles Toll Road, AVI toll collection is increasingly popular in a number of places:

- The world's first electronic toll collection took place in October 1987 in Ålesund, Norway. Though the traffic was modest with only 3,000 vehicles a day, 60% of the daily users were electronic tag holders (Waersted, 1992). In October 1988, electronic toll collection also started on a freeway in the eastern part of Trondheim.
- The 27-kilometer long Dallas North Tollway in Texas has a fully implemented and retrofitted AVI system of 60 lanes for toll tag users since August 1989. This system was installed by Amtech Corporation for free, hence users are charged *US\$2* a month for rental of the transponder and a premium of *US\$5* cents per transaction for using the nonstop technology (Roth, 1991).

- An example of smart card technology applied to a 'closed' toll road network has been implemented by Autostrade S.p.A. in Italy's autostrada connecting Milan, Florence, Rome and Naples. In operation since April 1990, the technology assures the privacy of its users by debiting the smart card at the appropriate toll rate when vehicles are driven past two charging points -- an entry and an exit point.²⁷
- On the ACESA highway in Barcelona, Spain, electronic toll collection started in April 1990 by the Autopistas Toll Authorities. A more full-fledged system operating on three highways is expected before the end of 1992.
- The Port Authority of New York and New Jersey switched over from a surface acoustic wave technology to microwave technology for buses as early as April 1988 using the Lincoln Tunnel. In Fall 1990, the Authority also began operation for passenger cars on the Goethals Bridge using a fully compatible system.
- The Esterel-Cote d'Azur Toll Agency, which operates the 250 kilometer long ESCOTA highway at Antibes, France also began operation with AVI in November 1990.
- The world's longest double-span bridge of 42 kilometers -- New Orleans' Lake Pontchartrain Causeway -- began operation in December, 1990, using the same (compatible) TollTag system as Crescent City Connection's.
- In January, 1991, the Oklahoma Turnpike Authority began operating the largest electronic toll collection system by installing it on 88 lanes and it expects to operate a total of 161 lanes when new turnpikes are completed in 1992. Charges for toll tag users are registered at freeway speeds whereas non-toll tag users are required to exit the

²⁷ The Telepass smart card technology is fully applicable to both 'open' barrier-type and 'closed' motorway network. With the latter system, the toll rate is simply calculated by the distance (or time) between two pricing points.

freeway to pay cash manually in order to avert any congestion and traffic back-up as a result of the toll transaction mechanism itself.

- Owned by a private company with the same name, Cofiroute -- a 730 kilometer [454 miles] highway in southwestern France -- has AVI equipment installed at two toll plazas near Tours, France, in May 1991.
- On September 22, 1992, the Harris County Toll Road Authority in Houston, Texas, started electronic toll collection on the 21-mile Hardy Toll Road and the 28-mile Sam Houston Tollway. Motorists who prefer to drive without stopping need only to set up an escrow account with the road authority for a rental fee of US\$1 a month for the use of an EZ Tag.
- An AVI system for special and commercial vehicles spanning Mexico from Tijuana to the border of Guatemala is expected to be installed by November 1992.
- An AVI license plate tag system is scheduled for 18 lanes of the Georgia Route 400 extension in Atlanta, Georgia by March 1993. Four of the lanes will be AVI express-type dedicated lanes, with a lane capacity of at least 1260 vehicles an hour (Spock, 1990). Under optimal conditions, they are capable of achieving the maximum freeway throughput of 1800 vehicles per lane-hour.
- In January 1992, various toll authorities in New York, New Jersey and Pennsylvania (known as the Interagency Electronic Toll and Traffic Management (ETTM) Group) issued a call for proposals for a standardized electronic toll transponder and reader system for the tri-state region, to be tested in 1993 and to be fully operational by 1995 (*Inside IVHS*, February 3, 1992). The prospect of driving nonstop from Philadelphia to New York City looms even larger. The consortium of toll agencies expressed a preference for read-write technology based on two-way communication even though a read-only technology based on one-way communication is considered acceptable. The

New York Thruway is the first among the interagency group to implement an electronic toll collection system named E-ZPass, to be operational in 1994-96 (*Inside IVHS*, May 26, 1992).

3) Combination of Manual and Electronic Toll Collection

i) The Oslo and Trondheim Toll Rings

45. The emerging popularity of AVI on toll roads and the success of the technology must have had an impact on proposals for electronic road use charging in Scandinavia. In particular, Oslo Toll Ring began using electronic toll collection with AVI technology in December 1990, following a period of manual toll collection beginning in February 1990. The toll ring surrounding the city imposes an admissions charge for motorists entering it round the clock at any time of the year. Having had the electronic technology in place, Oslo is currently debating the merits of switching from a flat toll to a time-differentiated charging scheme. Trondheim -- Norway's third largest city -- has begun in October 1991 electronic road use charging by daylight period to motorists who drive into the city. The operation of both the Oslo and Trondheim Toll Rings is the same as the practice of AVI on toll roads described above. Postpayment via conventional monthly billing statement and prepayment via electronic funds transfer are possible. Unlike most AVI systems on toll roads, the capital costs of Oslo and Trondheim Toll Rings include the construction of toll plazas for the installation of manual toll booths, automatic coin machines, and electronic toll collection. As a result of the plaza environment and a full video enforcement system for reserved lanes, the capital costs are relatively high. With an average daily traffic count of 210,000 and 50,000 during the hours of operation for Oslo and Trondheim Toll Rings respectively, the costs per transaction are NOK1.33 [US21.2 cents] and NOK1.17 [US18.7 cents] in 1990 prices respectively, which are much higher than simple AVI systems and twice as costly as manual systems.²⁸

²⁸ This result appears to be consistent with the findings of Hensher (1991), who concludes that the cost of installation *per lane* for *full* electronic toll collection in Norway is a third to a half of the cost of a manual toll collection system.

46. All three Norwegian toll rings -- Bergen, Oslo and Trondheim -- are primarily implemented for road financing. In particular, the Oslo Toll Ring was formed for the purpose of financing both roads and public transport in Oslo, with four fifths earmarked for the construction of roads and a fifth for busways. Similarly, the revenues of the Trondheim Toll Ring are used to finance infrastructure which promote public transport, cycling and walking (Tretvik, 1992).

47. The charging period for the Trondheim Toll Ring is Monday through Friday, 6 a.m. to 5 p.m. (except holidays), which is essentially pricing by daylight hours. The toll rate for (light) vehicles weighing under 3500 kg. [7716 lbs.] is *NOK*10 [*US*\$1.60] per inbound trip if it is collected manually and the rate for (heavy) vehicles weighing over 3500 kg. [7716 lbs.] is twice that of light vehicles. (Motorcycles are not charged at any time of the day and cars are not charged in the evening and at night.) Trondheim Toll Ring is unique because most (90%) of the users during the peak period (of 6 a.m. - 10 a.m.) and many (85%) of the users during the secondary peak period (of 10 a.m. - 5 p.m.) are electronic tag holders -- a fact that could be due to the free leasing of tags. Electronic transponder users opting for a prepayment (or a postpayment) option are entitled to a discount of 20% off (during the peak period) and 40% off (during the secondary peak period) of the manual toll collection rate of *NOK*10 per inbound entry during daylight hours, resulting in the toll rates of *NOK*8 and *NOK*6 respectively (Tretvik, 1992). (Further discounts are given to those who set up an account -- whether numbered or not -- with a deposit greater than *NOK*500 or even *NOK*2500 a month.) Ten of the 12 cordon entry points are not manned and the large fraction of AVI subscribers make the cost per transaction of the Trondheim Toll Ring comparable to that of the Oslo Toll Ring. A unique feature of the system is that a call box is available on all 12 entry points if a motorist encounters problems with the automatic coin machines, the use of magnetic strip credit cards, or the printing of delayed charges. As in the Oslo Toll Ring, enforcement is carried out by taking videographs of all vehicles passing through and issuing a penalty by mail of *NOK*250 [*US*\$16.89] for the violator. It appears the marked use of differential pricing for the heavy (electronic) users would

have some effect of changing the driving behavior of motorists whose trips are not as valuable -
- despite the fact that the charging period is nominally by daylight hours only.

48. Norway has had much experience with financing roads from tolls, as exemplified by the early implementation of the manually operated Bergen Toll Ring in January 1986. Residents in the Oslo and Trondheim vicinity were promised that the rate of constructing the planned road system could be achieved at twice the speed with toll financing. Even though the goal was not traffic restraint, the Oslo and Trondheim Toll Rings had the side effect of dampening travel demand somewhat. Despite the fact that the per trip toll rate for entering Oslo is *NOK*10 [*US\$*1.60] -- twice the rate for entering Bergen -- the initial estimate of the decrease in traffic is only about 5% -- less than Bergen's (Lauridsen, 1990; Larsen and Ramjerdi, 1990).

49. One natural question to raise is whether a system of 17 toll stations (which includes the entire construction cost of two toll plazas) is worthwhile or not. According to estimates made by Ramjerdi and Larsen (1991), the annualized cost for the Oslo Toll Ring is estimated to be *NOK*96.6 [*US\$*15.4] million.²⁹ The benefits of the toll scheme were estimated by using a simultaneous logit mode choice and traffic assignment model, under the assumption that trip timing, destination choice and location were fixed. For all practical purposes, motorists heading towards the CBD do not have a feasible alternative route to by-pass the toll. (Thus the first two assumptions which pertain to Oslo's cordon system can be contrasted with the Hong Kong zone-based ERP system, which is designed to influence route choice and the (re)scheduling of trips.) For the Oslo system, trip matrices are separated into four time periods -- the morning peak, the afternoon peak, the interpeak, and the off-peak -- and the choice of mode is between private auto and public transport.

²⁹ By assuming that the capital cost is amortized over 15 years and that the real discount rate is 7% (being the official Norwegian rate for public projects), the annualized capital cost of *NOK*255 million (plus the adjusted start-up cost of *NOK*5 million) comes to *NOK*28.55 million per year (slightly over the reported figure of *NOK*26.6 million in Ramjerdi and Larsen, 1991). Together with the annual operating cost of *NOK*70 million, the total annualized cost of the Oslo Toll Ring is *NOK*98.5 million. The benefit-cost ratios reported below are based on their reported figures, in contrast to the simple assumption of a capital recovery factor of 0.125, which is used as a yardstick of comparison across countries.

50. The economic benefits of the present Oslo Toll Scheme are based on: a) the savings in vehicle operating cost, and the savings in time cost to those travelers who stay and pay the cordon toll, less the *dis*benefits to those whose trips are not undertaken (hence the terminology 'net benefits').³⁰ The savings in operating cost are based on the savings in fuel consumption due to less engine idling time and stop-and-go traffic. In a situation in which private auto trips are dominant, as in Norway, the savings in travel time of the tolled less the welfare loss in consumer's surplus to those who are tolled off is shown to be less than the gross revenues of the project. The numerical estimates of the benefits are shown in Table 3, classified by time period, in millions of Norwegian kroner in 1990 figures (Larsen and Ramjerdi, 1990; Ramjerdi and Larsen, 1991; Larsen, Mathieu and Ramjerdi, 1991; and Ramjerdi, 1992, with corrections). The results clearly indicate that a round-the-clock, 365-day flat toll of *NOK*10 [*US*\$1.60] for light vehicles (and *NOK*20 [*US*\$3.20] for heavy vehicles) is non-optimal.³¹ During the peak period, the present 10 kroner toll does not cover the high marginal external congestion cost of *NOK*35.60 [*US*\$5.69] incurred during the peak when a vehicle drives inbound to the CBD. On the other hand, during the interpeak and the off-peak period, the current toll exceeds the marginal external cost of *NOK*3.80 [*US*\$0.61] and *NOK*1.40 [*US*\$0.22] respectively. The first set of results in Table 3 indicates that by imposing a lower than optimal toll during the peak, positive benefits of *NOK*38.3 [*US*\$6.1] million follow net of the welfare losses. Similarly, by imposing a higher than optimal toll during the interpeak and off-peak periods, negative benefits result. Thus the annual benefits for all time periods total *NOK*21.9 [*US*\$3.5] million. (Notice that the vehicle operating cost savings form a minor share of the benefits, in contrast to the Hong Kong ERP Scheme). Since the Oslo Toll Ring is designed for a mixture of manual and electronic toll collection, the lane capacity is about 800 vehicles per hour (see Spock, 1990). The delay caused by stop-and-go manual toll payment of 600,000 vehicle trips a week (assumed to be approximately 15 seconds per vehicle) is taken into account. By assuming a value of time

³⁰ The change in user cost formula employed by Ramjerdi and Larsen (1991) is based on Williams (1976).

³¹ Note that approximate usage had to be assumed for seasonal pass holders in 1990 and per trip charges will soon be made. Note also that the travel impact of the present toll was around 8%, 4% and 16% reduction during the peak, the interpeak and the off-peak period respectively, not taking into account the effect of seasonal pass holders (Larsen, Mathieu and Ramjerdi, 1991).

of *NOK*30 [*US*\$4.79] per hour and an average occupancy of 1.3, the aggregate annual delay at the toll plazas is on the order of *NOK*4.5 [*US*\$0.7] million. The estimated additional fuel cost due to stop-and-go traffic comes to *NOK*0.4 [*US*\$0.1] million per year. When combined with the cost of building the toll plazas to accommodate manual tollbooths and electronically controlled toll lanes of *NOK*96.6 [*US*\$15.4] million, the net benefits come to *-NOK*79.6 [*-US*\$12.7] million. (Note that the term 'net benefits' defined throughout this paper refers to benefits net of the implementation cost of a charging instrument (see footnote in Table 4).) The benefit-cost ratio, taking into account manual toll payment, is 18% and therefore fails a cost-benefit test. From a financial point of view, with adjusted annual toll revenues of *NOK*600 [*US*\$95.8] million, the revenue-cost ratio is 6.2, suggesting that governments would likely find toll financing a worthy pursuit.

51. Given that the electronics are already in place, a question that arises naturally is whether a large fraction of the benefits from road pricing could be reaped by imposing a crude cordon toll during the peak period only. For several years, it has been argued in Norway that a toll of about *NOK*20-25 [*US*\$3.2-\$4] would reduce traffic volume by about 20%. It was found that an inbound toll rate to Oslo of about *NOK*25 [*US*\$4] would approximate marginal external cost (Larsen and Ramjerdi, 1990).³² Further, the cordon boundary needs to be tightened in order to allow through traffic (a significant number of vehicles) to make detours and exercise route choice. Thus, by imposing a marginal congestion toll of *NOK*25 [*US*\$4] (or more precisely, the marginal congestion cost of *NOK*29.5 [*US*\$4.71]) on average during the peak that is somewhat optimal, the annual benefits come to *NOK*95.2 [*US*\$15.2] million. Notice that there are no benefits outside of the peak period since the marginal congestion cost of traffic in these other periods is close to zero. The higher benefits from imposing an improved 'optimal' cordon toll during the peak yields numerical benefits which are of the same order as the cost of operating the present toll scheme. However, with the inbound peak period only toll, just two short shifts of personnel are needed as opposed to personnel for 24 hours a day. Hence the reported figure

³² It is assumed that the cost of environmental pollution and road damage cost are covered by the high gasoline tax, so the marginal external cost during the off-peak period is nil (Larsen, 1991).

for the cost of toll collection is a lower amount of *NOK*70.0 [*US*\$11.20] million a year. The benefits, net of the cost of implementation, come to *NOK*20.3 [*US*\$3.2] million, with the benefit-cost ratio being 1.3 vis-a-vis a base case policy of doing nothing. Interestingly, the 'optimal' toll revenues are less than a third of the revenues derived from the present 'non-optimal' toll scheme in Oslo, but the revenue-cost ratio is 2.6. Notice that the cordon scheme differs from the idea of tidal flow charging, which is in accordance with the direction of peak period demand (as in Hong Kong's ERP Scheme B). This means that a round trip which incurs a marginal congestion cost of *NOK*25 [*US*\$4] in each direction -- one way during the morning peak and the other way during the afternoon peak -- is charged once, i.e., half the externality costs, unless it is a through trip across town. The benefit-cost ratio has increased more than six times whereas the revenue-cost ratio has decreased by 60%, suggesting that a social welfare maximizing toll may not necessarily be a revenue enhancing one. While an 'optimal' toll is two and a half times more than the present 'non-optimal' toll, it yields two-thirds less revenues to the government. If the current practice of earmarking toll revenues is continued, then it would seem 'fair' that those who cause congestion are the ones who should pay for them, while simultaneously enjoying the fruits of improved transport infrastructure.

52. If a motorist were to be charged for the marginal external cost he or she imposes on each link that is traversed in a given trip, the benefits from doing so would come close to a 'perfect' road pricing scheme. Thus the benefits of road pricing increased by six-tenths from *NOK*95.2 [*US*\$15.2] for the 'optimal' cordon scheme to *NOK*150.9 [*US*\$24.1] million for a 'perfect' road pricing scheme. The fact that, with 'perfect' road pricing the welfare loss for those who have not undertaken the trip is higher and the revenues lower suggests that travel demand is relatively elastic. The large benefits come about because of the avoided trips which would have caused high marginal external costs. As a result, the net benefits of the system increased further fourfold to *NOK*80.9 [*US*\$12.9] million and the benefit-cost ratio increased to 2.2. The costs of installing the electronic toll collection system route by route will clearly not be cheap. Hence the benefit-cost ratio will be less than 2.2. From a financial viewpoint, with 'perfect' road pricing, the revenues dropped from *NOK*180 [*US*\$28.8] to *NOK*152.1 [*US*\$24.3] million, and

the revenue-cost ratio decreased to 2.2. Thus, the fear of government collecting high toll revenues as one moves to a 'perfect' road pricing scheme does not seem to be borne out by these simulations. Estimated benefits are just below estimated revenues, suggesting that a benefit-maximizing pricing scheme is on average 'fairer' than it is generally perceived.

53. The Norwegian experience appears to demonstrate that toll financing and welfare maximizing objectives may not be correlated since they may go in opposite directions. That is, a (low) flat rate, 24 hour toll may maximize revenue but not net benefit. Per contra, a differential pricing strategy would enhance social welfare but not raise as much revenue. Data from Oslo has demonstrated that a 'perfect' road pricing scheme yields significantly higher benefits vis-a-vis a crude 'optimal' cordon scheme. By merely imposing a simple peak period toll, however, a nontrivial proportion of the benefits of a 'perfect' road pricing scheme and several times the benefits of the present flat toll scheme could be reaped too. Further, the cost of toll collection of such a crude 'optimal' scheme appears to be manageable for the size of a city such as Oslo. The simulation results from Norway also show that toll financing would require a lower toll whereas a welfare enhancing pricing strategy would suggest a higher toll. Still, a benefit-maximizing pricing strategy yields a benefit-cost ratio that happens to be the same as its revenue-cost ratio. Perhaps local authorities should only approve toll financing projects which pass the benefit-cost test.

54. The simulation results, which show that road pricing is 'fairer' than formerly perceived, have contributed to informed debate about the possible introduction of road pricing in Oslo. A white paper on road pricing is currently being prepared by the Ministry of Transport and the Norwegian Road Administration.³³

³³ As of January 1992, the toll for entering the CBD increased by one krone (from NOK10 to NOK11). Further, Oslo is looking into the possibility of the use of a debit card system rather than the current one-way AVI transponder system.

ii) Road Pricing on a Cordon Basis in Stockholm and Gothenburg

55. The application of AVI technology for electronic road pricing on a cordon basis in order to reduce congestion and environmental degradation was proposed for the Stockholm and Gothenburg regions in 1989. Since an electronic road pricing system is a fully-fledged AVI system extended to an entire area or city, with charging done on a point pricing basis each time a vehicle passes by an electronic reader, the costs would be higher than a simple AVI system for toll roads. In particular, the capital and operating costs hinge on the number of pricing points and transponder tags and the complexity or sophistication of the system. The Swedish proposals for the Stockholm and the Gothenburg regions are based on the principle of marginal social cost pricing, including the pricing of environmental pollution, and the agreement to channel the revenue proceeds to public transport and road construction. Three major political parties reached a final agreement in September 1992 to use a combination of manual and electronic toll collection system -- as in the Oslo Toll Ring -- to finance transport infrastructure for the Stockholm Region, with the possibility of introducing differential pricing (see Annex 3).

iii) The Hong Kong Electronic Road Pricing and Area Licensing Schemes

56. An earlier, full-fledged road pricing system on a multiple zonal basis was conducted in Hong Kong in 1983-85. Tested within a congested, multi-lane environment, the field trials based on a sample of 2500 vehicles proved that the Hong Kong Electronic Road Pricing System (ERP) was a technological success. Unlike the simple cordon-based electronic road pricing schemes proposed recently in Sweden, the system operates on five different time periods through a 12-hour day from 7 a.m. till 7 p.m.): the morning peak, the afternoon peak, the shoulder peaks, and the interpeak. Shoulder peak charging, immediately before and after the morning and afternoon peaks, was designed to deal with the boundary problems of Singapore's ALS by smoothing out the traffic. Shoulder peak charges are half the peak charges, whereas the off-peak period from dusk till dawn is not charged. Under the ERP proposal, all private cars in Hong Kong are required to be fitted with a nonremovable, videocassette-sized 'electronic number

plate' (weighing less than a kilogram) mounted underneath the vehicle.³⁴ Some road work was required for the 18 toll sites established for the pilot stage, involving reconstruction of the road surface, installation of electronic loops, and ducts for power and telecommunications cables underneath the road. (The direct (passive) charging technology available now is portable, pocketable and transferable, and does not necessarily require major road work.)

57. ERP has three pricing schemes. Scheme A is the simplest in design, and lowest in the level of charges, the number of zones and geographical coverage; Scheme B introduces tidal charging that matches the direction of peak demand; and Scheme C captures short trips as well as being the most complex in design and highest in the level of charges, the number of zones and geographical coverage. Imposing an optimal congestion toll of HK\$10 [US\$1.28] in 1985, achieves the theoretical maximal benefit level in the form of savings in travel time and vehicle operating costs, less reduced benefits for those travelers who are tolled off the road (see section on 'The Effects on the Tolled, the Tolled off and the Untolled' in Hau, 1992).³⁵ This annual benefit figure amounts to HK\$1,250 million [US\$160 million] in 1985. The simulation results, with their distributional impacts by mode for the reference year of 1991, indicate that Schemes A, B and C achieve respectively six tenths, seven tenths and three quarters of the maximal benefits associated with the theoretical optimum option of HK\$1,850 million [US\$237 million] in 1990 equivalent (see Table 4).

58. Since electronic number plate (ENPs) (together with an additional 10% cost for installation) were priced at HK\$460 [US\$59] each in 1985, the cost of the 210,000 ENPs make up about half of the system capital cost of HK\$240 million [US\$31 million].³⁶ Under the one-

³⁴ The now out-dated technology was first developed in the early 1970s by the U.K. Transport Research and Road Laboratory and used on the British Rail High Speed Train signaling system and the Glasgow Underground train control system (Transpotech, 1985, p. 3.5).

³⁵ The economic benefits from ERP are based on: 1) vehicle owners' savings in operating costs; 2) passengers' savings in travel time; and 3) public transport riders' savings (in time); less the welfare loss to those who are tolled off (i.e., the *disbenefits* from generated traffic). Hence Transpotech (1985) and Hau (1989, 1990) call these annual *net* benefits instead. In this paper, *net* benefits refer to benefits net of system cost.

³⁶ Since then, the price of a passive transponder has fallen by about two thirds and continues to fall.

horse shay assumption of a capital recovery factor of 0.125, the annualized capital cost is then HK\$30 million [US\$3.85 million] and the annual operating cost is HK\$19.80 [US\$2.54 million], representing three fifths and two fifths of the total annual cost respectively. The annual benefit-cost ratios are 14.7, 17.8, 17.8 and 24.1 for each of the three scenarios and the theoretical upper bound option.³⁷ With traffic growth and technological improvements, the benefit-cost ratios will most likely rise. The number of trips made by private cars is forecast to be 549,450 per week day in 1991 and the annualized capital and operating costs amount to just under HK\$50 million [US\$6.38 million] in 1985.³⁸ Using the number of operating days per year of 260, the system cost per transaction is HK\$34.9 cents in 1985 [US\$6.6 cents in 1990]. Even though over 10% of the capital cost and about 12-1/2% of the operating cost are required for the 'data capture' enforcement system, the cost per transaction would be even lower if account were taken of multiple transactions, that is, crossing several screenlines a day.³⁹

59. In comparison with other mechanisms, electronic road pricing fares well. The annual benefits of a car ownership fiscal restraint measure -- an indirect charging method levied on vehicle ownership via annual license fee discussed earlier -- amount to HK\$301 million [US\$38.6 million] in 1985, about a quarter of those of the optimum option and less than half of those of ERP Scheme A (see Hau, 1989, 1990).⁴⁰

³⁷ The slight difference in annualized costs for ERP Schemes A, B and C, reflect the fact that the capital cost varies somewhat in relation to the 130, 115 and 185 toll sites required respectively for each scheme.

³⁸ The average number of transactions per weekday was estimated by taking the proportion of those who 'stay and pay' (45%) and the total number of peak users (374,000) and interpeak users (847,000) remaining under Scheme A (Transpotech, 1985, p. 2.69 - 2.70). (Relative to Scheme A, Schemes B and C have less transactions due to the higher charges, so the costs per transactions would climb by 12% and 22% respectively.) The cost per transaction would be lower if one computes all the results on a six-day work week basis rather than five.

³⁹ If one were to use the number of vehicles forecast for 1991 of 275,000 (as opposed to using the 210,000 ENP figure on which the capital costs are based), the number of trips averaged per weekday by a motorist is exactly 2.00. This fortuitous result would make the Hong Kong figures comparable with manual charging and Singapore's ALS, etc., since the charges made elsewhere could be viewed as a round trip charge.

⁴⁰ The figure includes the disbenefits of those restrained or would-be car owners who are 'taxed off' from being able to own a private car (because of already existing hefty first registration taxes and annual license fees). The disbenefits amount to a total of HK\$244 million [US\$31 million] in 1985 (Harrison, 1986, Table

60. A Singapore-type area licensing scheme was actually tested and formally evaluated for Hong Kong in 1985.⁴¹ A typical supplementary fee of HK\$7 each [US\$0.90] for vehicles crossing a screenline (in either direction) which encircles the central business districts tallies to about HK\$20 [US\$2.56] each day in ALS fees. The annual benefits of area licensing amount to HK\$338.4 million in 1985 [US\$64.2 million in 1990 figures].⁴² This benefit figure from supplementary licensing makes up slightly more than a quarter (27%) of the benefits of the theoretical optimum option and less than half (46%) of those of ERP Scheme A. Despite the fact that these dollar benefits are slightly more than those of the car ownership fiscal restraint measure, the latter policy is a sledgehammer approach; it achieves a city-wide reduction in congestion by drastically *lowering* the level of car ownership (for four years) as well as eliminating economically worthwhile trips altogether. Further, the car ownership restraint measure is widely (and correctly) perceived to be inequitable by limiting household car ownership to the wealthiest, the top decile of the population (Hau, 1988).

61. The annualized cost of supplementary licensing as in Singapore is estimated to be in the range of HK\$10 - \$15 million in 1985 (or US\$1.90 - \$2.84 million in 1990 figures). The annual benefit-cost ratio for two separate zones (one on Hong Kong Island and the other in Kowloon) under an area licensing scheme is 22.5 to 33.8, even surpassing the benefit-cost ratio of 25 for the theoretical optimum of ERP -- the upper bound reference level of the benefits achievable under direct road pricing.⁴³ Suppose the benefits of time savings are ignored and sensitivity

3).

⁴¹ Note that the set of models used by Harrison (1986) and Harrison, Pell, Jones and Ashton (1986) allows for changes in mode choice, trip timing and destination, but not route choice. Most of the effects of the options tested are due to mode choice (90%), some of it to trip time change (10%) and a very minor part is due to destination change. Hence the flexibility of the models used in the exhaustive Hong Kong study on road pricing does allow for rescheduling, which overcomes one of Wilson's 1990 criticisms of the Singapore ALS.

⁴² Taxis are charged at HK\$4 per trip [US\$0.51] under supplementary licensing but are exempt under ERP schemes A, B and C.

⁴³ These numbers were adjusted from daily benefit figures (Harrison, 1986, Table 3) to annual figures by 188 days, possibly an underestimate. The factor of 188 was found by dividing the known aggregate annual benefit figure of ERP Scheme A of HK\$734 million [US\$94.1 million] (Transpotech, 1985, Table 8.5) by

analysis is performed, the annual benefits for the car ownership restraint measure, area licensing scheme and ERP Scheme A amount to *HK\$18.8 million* [*US\$2.41 million*], *HK\$56.3 million* [*US\$7.22 million*], and *HK\$281.5 million* [*US\$36.09 million*] respectively. Note that the monetary benefits alone make up 6%, 17% and 38%, respectively, of the total economic benefits. In other words, the monetary benefit-cost ratio for area licensing ranges from 3.8 to 5.6, and for ERP Scheme A the benefit-cost ratio is 5.7 coincidentally.

62. The cost per transaction is conservatively estimated to be *HK\$7.0 to 10.5 cents* per transaction [*US\$1.3 to 2.0 cents*] in 1985, making area licensing the least costly scheme vis-a-vis ERP. Because of its very low cost -- both capital and recurrent -- the revenue-cost ratios bracket the range of 12.5 and 18.8. However, it turns out that a single cordon could not be found to neatly encompass the congested areas of Central District in Hong Kong (but could be for Tsim Sha Tsui in Kowloon). Thus, this potentially attractive area licensing scheme faced practical difficulties of implementation and ranked less favorably relative to ERP. Further, other factors including: the single coarse level of charge, the long duration (12 hours) of a unitary charging period, the preponderance of overnight parkers being garaged within the zone, and the small level of benefits obtainable under supplementary licensing vis-a-vis the ERP Schemes, all contribute to ALS being rejected in Hong Kong.

63. From the municipality's point of view, the revenue-cost ratio is perhaps the more appealing figure. With the auto ownership restraint measure, the additional cost that the government incurs when raising first registration taxes or annual license fees is negligible, given that the administrative structure is already established. Thus, raising (car) taxes has an almost infinitely high financial rate of return and rate of return alone would not be an appropriate statistic to compare road pricing measures. Note also that these indirect fiscal restraint measures are crude instruments with which to tackle congestion. Area licensing schemes' rate of return

the daily benefit figure of *HK\$3.898 million* [*US\$0.50 million*]. In a discussion with Bill Harrison, it was suggested that the simulation results for the 1991 reference figures were converted to 1985 dollar terms, under the assumption that real income (and hence time savings) increased by 33% during that time period.

would be very high because of their low capital cost (this is confirmed by the Singapore evidence) and, provided that the geographical conditions are not insurmountable, these schemes would appeal to local transport authorities facing hard budget constraints. The practical ERP Schemes possess revenue-cost ratios that range from 8 to 10, whereas the theoretical optimum ERP option yields the revenue-cost ratio of 19 -- the highest of all the measures considered.

64. With the 1989 Green Paper on Transport Policy, the Hong Kong Government again tested public opinion on electronic road pricing under the guise of 'area pricing'. It turns out that the Second Comprehensive Transport Study (CTS-2), which forms the basis of the consultative Green Paper, shows that area pricing is in fact ERP Scheme B resurrected (Transport Department and Wilbur Smith and Associates, 1989, Figure 9.3 and Table 9.5).⁴⁴ A slightly lower charge (two thirds) of the original 1985 ERP Scheme B proposal was simulated. The CTS-2 concludes that area pricing is technically the best means of combatting congestion in selected areas. Dogged by continuing concerns about the potential intrusion of privacy by 'big brother' and accentuated by the issue of 1997 (when Hong Kong will be returned to China), the Hong Kong Government revealed in the ensuing White Paper of 1990 that it has decided to retain area pricing by electronic devices as a long-term option and to monitor the technological developments and their applications elsewhere. In early 1992, the Government began testing state-of-the-art automatic vehicle identification technology using the Amtech one-way radio frequency-based and the PREMID stored value, two-way radio communications systems for electronic toll collection at the Aberdeen and Cross Harbour Tunnels. Since April 1992, a pilot project has been operating at the Aberdeen Tunnel on Hong Kong Island, with full commercial operation expected in April 1993 pending legislative changes to the tunnel ordinances and by-laws. Given Hong Kong's previous experience, the publicly owned but privately operated tunnel companies have offered their clients full protection from invasion of privacy through the establishment of numbered account arrangements. If either of the AVI technologies is adopted,

⁴⁴ Area pricing is a variant of ERP Scheme B because it extends the charging days to include Saturday (since Hong Kong does operate on a six-day work week). Hence all the above analysis on ERP applies and is quite timely. The reference year is changed from 1991 to 1996.

the initial flat-rate tolls may give rise to differential tolls later -- the key to combatting congestion.

iv) Congestion Pricing in New Toll Roads of Orange County, California

65. Given the political difficulties of implementing road pricing, a concept that has gained momentum recently is the deployment of state-of-the-art technology for implementing congestion pricing on private toll roads. Motorists would not feel coerced -- as with road pricing -- into paying for the use of a road hitherto *not* regarded as free when offered the choice of using a freeway and a feeway. As part of the advent of the privatization of highways in California (provided for in California's Assembly bill 680), the Department of Transportation awarded four franchises in September 1990 to the private sector to construct and run toll roads in Orange County, California (*Inside IVHS*, February 4, 1991). The US\$88.3 million State Route 91 (the Riverside Freeway) median project will have four additional lanes of road capacity built, operated by a private firm, and transferred to the state after 35 years -- known as a Build-Operate-and-Transfer (BOT) scheme. With a rate of return regulation of 17% - 20% cap imposed on the company's capital costs, motorists using the heavily congested corridor are expected to pay electronically (or manually) about US\$2 during the peak and US\$1 during the off-peak when traversing the ten-mile stretch of highway. Expected to be operational by 1994, average daily traffic volume is estimated to be 30,000. The SR91 project is viewed as the first test of AVI and congestion pricing concepts in the U.S. (*Public Works Financing*, November 1991).

B. On-Vehicle Metering

66. Direct charging can either take place off a vehicle or with an on-vehicle metering system. The modern equivalent of a mechanical on-vehicle meter is an on-board unit consisting of a smart transponder and a smart card reader, the technology of which was described in the previous section. There are two types of pricing schemes, point pricing and continuous pricing by time and distance. Whenever a vehicle passes a pricing point, the vehicle is charged for crossing it, regardless of whether the motorist encounters another charging point. This type of

charging is in contrast to the continuous type, which relies on at least one other pricing point to clock in or out with -- so charging is based on distance or travel time.

i) The Comprehensive Electronic Road Pricing Scheme of the Netherlands based on Smart Card Technology

67. In Europe, until recently, the most rapid progress in road pricing was made by the Netherlands. In 1988, the Dutch Ministry of Transport established a special task force for *Rekening Rijden* -- which literally means travel accounting or road pricing -- to investigate the feasibility of introducing a comprehensive road pricing experiment scheduled to start in 1992, with complete coverage of the Randstad Area by 1995. Having evaluated various state-of-the-art technologies for electronic toll collection, the Dutch Government decided to pursue the use of smart card technology in electronic road pricing for a zonal-based system.⁴⁵

68. As with almost all other major metropolitan areas, the growth in travel demand in the Randstad exceeds the growth in road space. In 1990, car usage was forecast to increase by over seven tenths between 1986 and 2010.⁴⁶ The Randstad area -- an urban (and interurban) agglomeration encompassing the four major cities of Amsterdam, Rotterdam, the Hague and Utrecht, with a total of six million people (over four tenths of the country's population) -- was targeted to be the testing site for comprehensive road pricing. Clearly laid out in the

⁴⁵ To maintain consistency throughout this paper, I define the term 'cordon-based system' as referring to a system of cordons or rings with concentric circles and the term 'zonal-based system' as referring to a system of zones that are not concentric in nature, as with the Hong Kong ERP Scheme. With such a definition, charging is not necessarily imposed on travel within both cordons and zones. By contrast, the Dutch Government calls their system a (multiple-) cordon based system as distinct from a zonal-based one because they would impose charges for travel *within* a zonal-based system (Stoelhorst and Zandbergen, 1990). This distinction is not semantic in that travel within a zone could cause a great deal of congestion, and that the electronics needed would be much broader in coverage and sophistication, adding to enforcement costs. I am indebted to Heero Pol for his comments and for providing me with the quantitative information on the Dutch proposal.

⁴⁶ The 72% growth in car usage is broken down as follows: population growth (20%), growth in car ownership (30%) due to increases in income and employment, growth in female participation in the driving population (10%) and increase in the level of transport service (12%) (Pol, 1991).

"Programme of Requirements for the Road Pricing Scheme", the objectives of road pricing are to: a) reduce the growth of car use generally, as measured by total vehicle-kilometers traveled, by 14 percentage points (from 72% to 58%), and that of car use during the peak by 30 percentage points (from 72% to 42%), b) reduce waiting time costs by 19%, so that the area would be almost congestion-free by 1996, and c) use part of the revenues for the financing of roads. The scheme's requirements also specify that the revenues raised must be high enough to repay several privately-financed tunnels, and that excess road pricing revenues should be transferred back to the motorist somehow, such as in the form of a reduction in annual vehicle ownership taxes. In addition, the attributes of a 'good' road pricing system (including enhanced efficiency, flexibility, simplicity, transparency, privacy, reliability, security and enforcement, prepayment option, occasional visitor handling, minimal road work, compatibility, and passing both benefit-cost and revenue-cost tests, (as listed in Table 2) are almost all laid down in the general requirements of the Dutch scheme and are mostly met with smart card technology. Even the document for the functional design specification for an automatic charging system spells out the performance specifications in some detail (Intercai, 1989). Specification particulars include the need for the system to handle: a) normal traffic flow and speeds (from 0 to 160 kph for a maximum of six undivided lanes; b) normal road capacity of 2000-2400 vehicles per lane-hour; c) a transmission error rate of less than one in a million; d) a transmission speed for the communications link exceeding 100 Kbits per second (achievable by microwave technology in the GHz range); and e) a smart card that has sufficient memory capacity to store at least 200 transactions.

69. The charges were designed to be *Dfl*3 [US\$1.65] per passage during the peak hours of 8:30 - 9:30 a.m. and 4:00 - 6:30 p.m. and *Dfl*0.30 [US\$0.16] during off-peak hours.⁴⁷ The effects of road pricing during peak-hours for the reference year of 2010 are: a) the decrease in total kilometers traveled of 80% (due to suppressed trips, shorter trips and trips undertaken to alternative destinations); b) a rescheduling of trips to off-peak hours of 5%; and c) a change in

⁴⁷ For time-of-day pricing, other schemes such as setting some other periods at half the peak charges were also tried out.

mode of 15%. The revenues are estimated to be *Dfl*300 [*US*\$165] million per year. From 1992 to 2010, the time savings amount to *Dfl*10,000 [*US*\$5,495] million for those who are tolled and the loss of surplus amounts to *Dfl*440 [*US*\$242] million for those who are tolled off the road (and on to public transport, say). Thus the benefits come to *Dfl*9,560 [*US*\$5,253] million in present value terms in 1992. With the total system cost of *Dfl*2,200 [*US*\$1,209] million for the 18-year period, the net benefits are *Dfl*7,360 [*US*\$4,044] million and the benefit-cost ratio is 4.3. Also estimated are external benefits such as a decrease in road maintenance costs of *Dfl*450 [*US*\$247] million and environmental benefits valued at *Dfl*400 [*US*\$220] million. If one were to include these other external costs and benefits (heretofore not included in other schemes such as Oslo Toll Ring), the social benefits come to *Dfl*10,850 [*US*\$5,962]. External costs were estimated to include an increase in the public transport subsidy of *Dfl*700 [*US*\$385] million, migration costs of *Dfl*700 [*US*\$385] and prosperity losses of *Dfl*2,000 [*US*\$1,099] million. Thus, the social net benefits come to *Dfl*4,810 [*US*\$2,643] million and the *social* benefit-cost ratio is 3.2.⁴⁸

70. For purposes of comparison with the other charging mechanisms presented here, conversion to annualized figures is necessary. The capital cost for implementing the smart card technology is estimated to be *Dfl*500 million in 1991, which is equivalent to an annualized capital cost of *Dfl*62.5 [*US*\$33.3] million in 1990 figures.⁴⁹ Since the annual operating costs are estimated to be *Dfl*55 million in 1991, the total annualized costs (including enforcement costs) amount to *Dfl*117.5 million in 1991 [*US*\$62.68 million in 1990 figures]. With the total number of transactions estimated to be 500 million per year in the full Randstad area, the cost per transaction comes to roughly *Dfl*0.24 in 1991 [*US*12.5 cents in 1990 figures]. Thus the cost

⁴⁸ The social *net* benefit-cost ratio is 2.2. In our context, the relevant comparison of benefit-cost ratios requires that the system cost of alternative congestion charging mechanisms be placed in the denominator and all other costs be counted as negative benefits in the numerator. Heero Pol, Dutch Ministry of Transport and Public Works, estimates that the cost per transaction of AVI and smart card technology are approximately the same.

⁴⁹ The capital costs include the estimated cost of 4 to 5 million smart cards. I am grateful to Heero Pol, Chairman, Toll Collection Project, for providing the above figures and for his insightful comments on the charging mechanisms (see Pol, 1992).

per transaction is on the order of twice the cost of the scheme for Hong Kong, reflecting the higher cost of microelectronics of a two-way smart card system vis-a-vis a one-way tag-based system. The annualized benefits from time savings of those tolled, net of the disbenefits of those tolled off, are about *Df*1530.6 million per year [or *US*\$283.0 million in 1990 figures], with an annual benefit-cost ratio of 4.5, which is close enough to our previous benefit-cost ratio of 4.3 calculated using total figures.

71. As opposed to road pricing, one could attempt to reduce congestion by the unpalatable alternative of constructing roads, at a cost of *Df*30 [*US*\$16.5] billion, up till the year 2010 (Ministry of Transport and Public Works, 1989). The revenue-cost ratio of electronic road pricing using smart card technology is estimated to be 2.6, and the toll revenues collected would help alleviate the pressing demands for road construction somewhat. Nevertheless, even though the Dutch Government made a policy decision in 1988 to introduce a comprehensive road pricing scheme for the Netherlands for the period 1992 to 1996, the scheme floundered on political grounds (Catling, 1990). Apparently, the dedication of toll revenues did not sufficiently assuage the car lobby's fear that this might be yet another revenue-raising device on the part of the government. Further, smart card technology requiring two-way radio communications was not considered sophisticated enough in 1990 to warrant a go-ahead for the road pricing scheme.⁵⁰ Thereafter, the Dutch Government had chosen to reduce the scale of the first phase of the road pricing project by limiting it to electronic toll collection at the tunnels under the Project Toll Ring. On April 27, 1992, the Minister of Transport announced that a system of supplementary licensing will be instituted for motorists using the main road network during the peak period instead. It is expected that eight tenths of the motorists would purchase seasonal passes, but the use of seasonal passes may dampen the desired effects (as discussed before in Annex 2).

⁵⁰ One of the specifications sought for a smart card is that it should contain at least 200 transactions, whereas smart cards produced for a large French banking system at the time could only contain 175 transactions, even before considering the transponder component required for identifying objects which are in motion (Intercai, 1989).

ii) Congestion Metering in Cambridge, England

72. Cambridge, England is currently in the design stage of a road pricing scheme based on smart card technology. A prototype on-board unit (transponder plus smart card) -- and its miniaturized version -- is currently being developed as part of the *Pricing And Monitoring E*lectronically of Automobiles (PAMELA) project, which is one of the projects under the European Community's *Dedicated Road Infrastructure for V*ehicle Safety (DRIVE) research programme⁵¹. Full scale field trials are expected to begin in 1993-94, with public consultation to be sought in 1995-96 for a decision of whether to go ahead with road pricing or not.

73. The scheme works as follows. A cordon is placed around the City of Cambridge and beacons are strategically installed at 17 radial roads which fully control the gateway to the city. Whenever an automobile equipped with an on-board unit containing a valid smart card passes a roadside beacon when 'congestion' occurs, a 'congestion unit' of 20 pence [US36 cents], say, is debited electronically on the smart card (Oldridge, 1990). Simultaneously, traffic information by lane is also collected by a real-time data-concentrator, which aids in monitoring the congestion situation. However, the key difference between the Cambridge road pricing concept and all other road pricing systems is that the former is based on *ex post* pricing and the latter on *ex ante* pricing. Congestion charging, in this case, is applied literally -- as and when congestion occurs, without any prior notification -- regardless of whether avenues of escape are available at a congested bottleneck. When an equipped automobile enters the city during the peak hours, the in-vehicle unit is triggered on and is turned off only upon exit or whenever the engine is shut off. Thus the Cambridge system is based on continuous pricing rather than on point pricing, which was the basis of the Dutch smart card system and most other AVI systems.⁵² A 'congestion unit' is debited on a smart card when one of the following

⁵¹ A microwave communications link using a 2.45 GHz transmission frequently was already tested at Newcastle in 1990 (Hills and Blythe, 1990; Blythe and Hills, 1991; Thorpe and Hills, 1991).

⁵² A similar device called Timezone, which charges for congestion on a continuous pricing basis, is designed by GEC-Marconi. The trial for testing the electronic equipment is to begin in the London Burrough of Richmond in 1991.

provisional conditions defining 'congestion' is met: the threshold of a pre-specified speed (e.g. 6 mph within a third of a mile or 3 minutes for every half kilometer is reached; or more than four stops are undertaken within a third of a mile).⁵³ Even though *ex ante* pricing is on an *expected* congestion rather than *actual* congestion basis, it is consistent with the dictum that price signals be made known to the consumer-traveler beforehand, with the objective of transmitting scarcity values to the rational consumer and the aim of impacting modal split. While the smart card component assures privacy, *ex post* congestion-based pricing does not affect or modify travel behavior as effectively as *ex ante* pricing would.⁵⁴

74. The plan by the Cambridgeshire County Council is to distribute on-board units with the transponder free of charge to regular users, whereas occasional visitors to the city will have to pick up daily passes from automatic machines at the entrances to the city. The revenues from congestion charging are earmarked to improve public transport, for instance, by the construction of a light rail transit system. While it is unclear at present whether this demonstration project will eventually be implemented, the Secretary of Transport in the United Kingdom has decided that London's congestion situation has become intolerable. The U.K. Department of Transport has therefore commissioned MVA Consultancy to embark on a three-year study beginning November 1991 on mainly electronic approaches to tackling congestion in London. Other cities such as Edinburgh are also investigating the feasibility of charging for congestion by electronic or other means. Quite a few are convinced that it is only a matter of time before electronic road pricing becomes a reality in Europe.

⁵³ At the time of this writing, Brian Oldridge informs the author that the City of Cambridge has abandoned the latter charging criterion. Still, it is possible that problems with safety may arise if vehicles reduce their tendency to stop at pedestrian crossings in order to attain an average threshold speed.

⁵⁴ One of the interesting aspects about the original proposal is that whenever the stored value of a smart card expires and a vehicle's engine is turned off for more than a minute, the engine electronics (or gas supply) is cut off for enforcement purposes! This is done to ensure that users recharge their smart cards at filling stations, for instance. Although this would reduce the cost of enforcement to society, this tactic may possibly pose as an unnecessary hurdle to political implementation.

iii) The Singapore Electronic Road Pricing System

75. Finally, it is worth mentioning that Singapore -- the pioneer in road pricing -- has taken the bold step of upgrading its simple labor-intensive area licensing scheme into a capital-intensive electronic road pricing system, to be operational by 1995. The initial goal is to turn the 26 manually controlled gantry points of the ALS into electronically controlled ones, with the intention of eventually turning the scheme into a more sophisticated ERP system. After inviting tenders for both an AVI and smart card system, authorities have now adopted smart card technology as the basis of their electronic road pricing system. In response to the government's first call for tenders, about 30 international companies submitted proposals, with five finalists being chosen. The installation cost, including an electronic enforcement system, in the mid-price range, is S\$80 [US\$44.2] million and a five-year maintenance contract is about S\$21 [US\$11.6] million.⁵⁵ Assuming that budget authorities act conservatively and aim for this median bid, the cost per transaction is S72.7 cents [US40.2 cents], under the assumption that the morning (7:30 - 10:15 a.m.) and afternoon (4:30 - 6:30 p.m.) peak traffic volumes still remain at the level of 69,000 in 1990 (Public Works Department, 1990).⁵⁶ On the other hand, if the current average daily traffic count of 300,000 during the day (6 a.m. - 8 p.m.) is used when electronic road pricing becomes more encompassing, the cost per transaction is S16.7 cents [US9.2 cents].⁵⁷ The capital costs include the costs of smart card units for 520,000 automobiles. Vehicles from foreign countries are not exempt from ERP and those who intend to drive into the Restricted Zone during peak hours are expected to obtain temporary tags at commissioning stations for

⁵⁵ The bids for the installation costs range from a low of S\$41 [US\$22.7] million (by Philips) for a simple AVI system to a high of S\$164 [US\$90.6] million (by the joint venture of United Engineers and Vapor Canada, Inc.) for a sophisticated smart card system, with numerous add-on options. The bid submitted by United Engineers and Vapor Canada, Inc., for a more basic smart card system was S\$98 [US\$54.1] million. The five-year maintenance contracts for each comes to S\$13 [US\$7.2] and S\$14 [US\$7.7] respectively in 1990 figures.

⁵⁶ The number of operating days in the year is assumed to be 283, as with ALS. The corresponding costs per transaction for the low and high bids are S39.6 cents [US21.9 cents] and S119.3 cents [US65.9 cents] respectively.

⁵⁷ The corresponding cost per transaction for the low and high bids are S9.1 cents [US5.0 cents] and S27.4 cents [US15.2 cents] respectively.

foreign vehicles. Due to the stringent performance specifications set by the Singapore Government, the wide variation in the submitted bids, and apparent failure to agree on the commercial terms of the lucrative market between the negotiating parties, new tenders were sought in March 1992 based on revised specifications for a smart card system. Work is expected to begin on ERP in Singapore by the end of this year.

V. SUMMARY AND CONCLUSIONS

76. The gamut of indirect and direct congestion charging mechanisms has been reviewed here. Indirect charges via vehicle ownership such as a purchase tax and annual license fees suppress worthwhile trips in uncongested areas and are considered sledgehammer approaches to dealing with congestion. Charges imposed indirectly on the amount of vehicle use via the fuel tax fail to differentiate road use between congested and uncongested times and places. A parking charge, by nature, can deal only with stationary vehicles and fails to tackle through traffic. Also, it is likely that too large a discrepancy between public on-street parking charges vis-a-vis private off-street parking rates would exacerbate the congestion situation further, especially when vehicles cruise around in search of cheaper parking places. However, in many downtown areas where employer-subsidized parking prevails, parking *pricing* could serve as a vital complementary measure to road pricing. What remains are essentially four congestion pricing instruments: supplementary vehicle licensing, cordon pricing via manual tollbooths, direct charging via automatic vehicle identification (AVI) and smart card technology. Each of these instruments is dealt with by an in-depth case study analysis.

77. Although supplementary licensing is classified as indirect charging in Table 1, it can be thought of as cordon pricing applied directly to vehicles which are in motion, with the possible option of undertaking multiple entries (see footnote 9). Even though manual and electronic toll collection mechanisms are not charging instruments per se, they do form the rudiments of cordon pricing via manual tollgates and electronic road pricing via AVI and smart card technologies, and hence are summarized alongside the four charging instruments in Table 5. (The grouping of the criteria for choosing a technology vis-a-vis the others is based on the perspective of: the road user, the road authority and society. A charging instrument is evaluated on each of the twenty criteria on the basis of a 'high' (coded by a white box), 'medium' (black and white box) or 'low' (black box) ranking as it pertains to the specific illustrative case study. Because of the potentially divergent objectives of the different parties, an unequivocal result of one instrument dominating another is unlikely to emerge.)

78. Tollbooths suffer from being land intensive, labor intensive (due to the hiring of toll operators) and time intensive (due to the queuing delay to motorists), and are not ideal for congestion charging in and of themselves. The process of stopping and paying disrupts traffic flow and lengthens queues, defeating the ultimate goal of alleviating congestion. However, cordon pricing as in the Bergen Toll Ring could serve as an effective instrument of charging for congestion since half the toll lanes are reserved for the use of seasonal pass holders who travel through the pricing points at regular highway speeds. Enforcement of those driving on reserved lanes is carried out by periodic videographs of vehicle license plates, just as radar technology is a socially acceptable tool to catch speedsters. The area licensing scheme (ALS) requires that vehicles entering the central business district during peak hours display a monthly or daily license prominently, with enforcement being undertaken at gantry points by traffic wardens who perform visual checks on the nonstop traffic. Enforcement of ALS would be prohibitively costly when carried out at motorway speeds but would likely involve relatively low cost in a standard congested urban environment with limited entry and exit points. As a measure of the technical efficiency of a system, consider the long-run cost of operating a congestion charging mechanism, which includes amortized capital and operating costs. Based on a variant of cost-effectiveness analysis, the cost per transaction is then used as an index of comparison among technologies: it indicates that supplementary licensing is the lowest, even lower than that of cordon pricing as in Bergen. The Oslo Toll Ring is designed for the purpose of electronic and manual toll collection, and the construction of large toll plazas accommodating both involves relatively high capital cost. (Note also that a flat rate, 24-hour toll used by a (standard) manual and electronic toll collection system such as Oslo's is not welfare enhancing. The use of such a system would improve social welfare if a differential pricing strategy were adopted by simply implementing a crude peak period toll). However, merely retrofitting an existing toll plaza setting with electronic toll equipment would not involve high capital cost, as the Crescent City Connection case clearly demonstrates. By the same token, electronic road pricing (ERP) is thus electronic toll collection *writ large* and made obligatory on vehicle owners within a jurisdiction. Even though the cost of the electronic equipment for standard AVI based on a one-way communication link is not considered trivial, the benefits are a multiple of the cost. As the sensitivity analysis performed on the Hong Kong ERP Scheme clearly demonstrates, even after excluding time

savings on philosophical or other grounds, the savings in operating cost still yield benefit figures that are considerably greater than the system cost. Using yet another yardstick, the cost per transaction is also found to be low.⁵⁸ The much touted invasion-of-privacy issue that plagued the Hong Kong ERP scheme in the past can now be dealt with by providing road users access to confidential "numbered account arrangements" with prepaid cash deposit. The capital cost of electronic road pricing with smart card technology for the Comprehensive Road Pricing Scheme of the Netherlands is higher than AVI alone technology, but the benefits outweigh the cost also. Put together, the benefit-cost ratio remains respectable. Still, the cost per transaction of smart card technology -- based on a two-way communication link -- is about twice that of AVI alone technology, and, even though the cost per transaction can still be regarded as acceptable, this technology is still not widely used on a commercial basis. Nevertheless, rapid progress in microelectronics, cryptology and microwave technologies will continue to yield large-scale economies in the manufacturing of AVI equipment, read-write transponders, smart cards and the hardware and software that go with them. It may very well be the case that the cost per transaction of smart card-type AVI technology will soon approach that of AVI alone technology.

79. What emerges from a quick perusal of Table 5 is that electronic approaches of direct road use charging are superior to manual approaches, on average, whether from the perspective of a road user, road authority or society. Among these broad categories, ERP using AVI alone technology is ranked higher than ERP using smart card -- given the state of current technologies in 1992 -- based on an unweighted index of all the criteria (see Table 5). In general, ALS is superior to cordon pricing using manual tollbooths. Hence, if budgetary conditions allow it, the feasibility of implementing ERP ought to be investigated. However, if budget is tight, then ALS (with its low cost and correspondingly high benefit-cost ratio) ought to be seriously considered. If one is given only a single criterion to pick (out of the 20 criteria), I argue that the most important measure (although not an all-inclusive one) is the passage of the benefit-cost test.

⁵⁸ Note that this is so despite the fact that the standard capital recovery factor used to compare widely differing technologies is biased *against* capital-intensive AVI technology possessing long life.

Nevertheless, by pursuing the multicriteria analysis introduced here, the road authority or decision maker could -- on the basis of other criteria listed -- choose from amongst a variety of congestion charging instruments.

Recommendations of Congestion Charging Mechanisms for Developing Countries

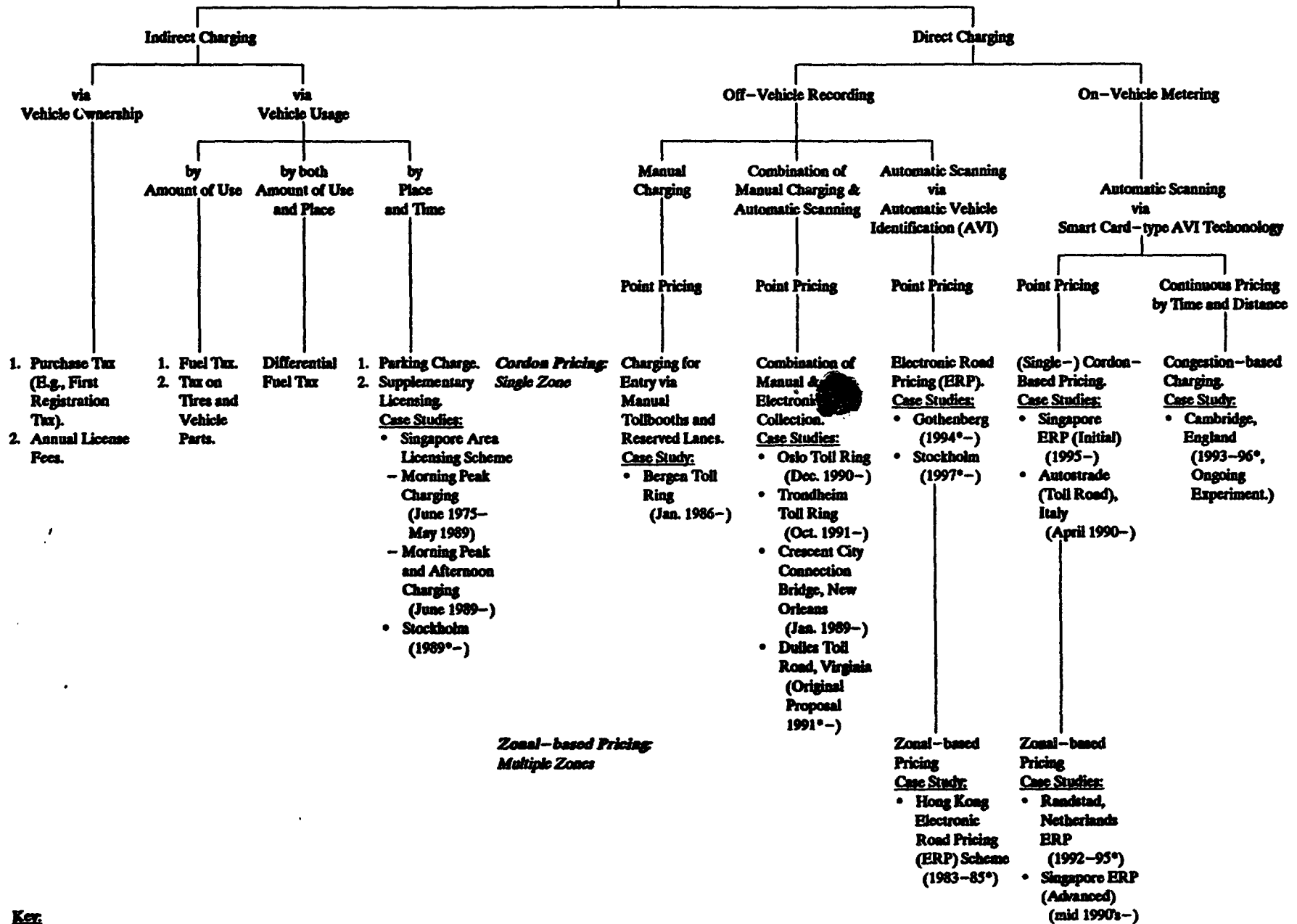
80. While the principles of road use charging enunciated here are applicable worldwide, the following guidelines are put forth with developing countries in mind:

- On the basis of benefit-cost calculations, the labor-intensive technology of supplementary licensing outranks the capital-intensive technology of electronic road pricing via AVI and is especially suitable for those developing countries that have a pool of unemployed work force and limited gateways. (A fairly reliable guide to the appropriateness of implementing ALS in a particular city is the citizenry's adherence to general traffic regulations.) This charging instrument is definitely worth revisiting, with the proviso that improved alternatives such as public transport and bypass routes be offered (as in the Singapore ALS).
- Cordon pricing via standard manual tollbooths and unattended reserved lanes (as in Bergen) -- supplemented by periodic videographs -- may yet prove to be a worthwhile, labor-intensive technology to consider in developing countries.
- The lesson of using electronic toll collection as in the Oslo Toll Ring amply demonstrates that it is the peak/off-peak pricing strategy, rather than the electronics per se, that is benefit enhancing (as opposed to being merely revenue enhancing).
- Electronic road pricing via AVI alone technology is a viable alternative for the newly industrializing economy whose standard of living is rising but whose rapid urbanization and motorization growth rates are a major problem.

- Smart card technology is not widely available on a commercial basis in roads and hence is not yet recommended for developing countries at this time, even though Singapore has already actively sought international tenders (as a source of technology transfer) for the implementation of its Electronic Road Pricing system with smart card by 1995. Technological breakthroughs will continue to make this electronic equipment worthwhile on both economic and financial grounds. In the interim, the use of two-way microwave read-write transponders that are less costly and yet fully protect privacy can be considered.
- The disposition of the revenues collected from road pricing is crucial to its success -- be the funds raised by electronic means or not -- and should be explicitly laid out to the public. Based on both experience and conceptual grounds, it appears that earmarking of the proceeds from road pricing would serve as an important prerequisite to the actual implementation of (Bank-mandated) marginal cost pricing in the road sector.

Timothy D. Hau

Table 1
Methods of Road Use Charging



Key:
Proposed systems are denoted with asterisk (*).

Table 2: Criteria for a 'Good' Road Pricing System

From Users' Point of View (1-4):

- 1. User-friendliness (Simplicity)**
- 2. Transparency (via *Ex Ante* Pricing)**
- 3. Anonymity (Protection from Invasion of Privacy)**
- 4. Prepayment/Postpayment Option for Charging**

From Road Authority's Point of View (5-11):

- 5. Enhanced Efficiency via Direct Charging**
- 6. Flexibility (Responsiveness to Demand)**
- 7. Reliability**
- 8. Security and Enforcement:**
 - a. Protection from Theft**
 - b. Protection from Fraud**
- 9. Provision for Occasional Visitors**
- 10. 'Market' Price as an Investment Signal**
- 11. Passage of Revenue-Cost Test**

From Society's Point of View (12-20):

- 12. Passage of Benefit-Cost Test**
- 13. Minimum of Road Work and Environmental Intrusion**
- 14. Provision for Mixed Traffic**
- 15. Handling of Transitional Phase**
- 16. Compatibility with Other Systems**
- 17. Modularity to Add-on Options (e.g. automatic route guidance)**
- 18. Tolerance to Culture of Non-compliance**
- 19. Tolerance to Varied Geography**
- 20. Fairness and the Availability of Alternatives**

Table 3: Benefits, Costs and Revenues of Various Cordon Toll Schemes in Oslo, by Time Period, per year (in millions of 1990 Norwegian kroner)

1) Results of the Present (Non-optimal) Cordon Toll Scheme in Oslo (i.e., a 24-hour Inbound Flat Toll of NOK10 [US\$1.60]) vis-a-vis the Base Case of No Toll

	Savings in Operating Cost	Savings in Travel Time	Welfare Loss of Surplus	Total Benefits
Peak Periods	2.4	42.1	-6.3	38.3
Interpeak Period	0.2	5.0	-7.0	-1.7
Off-peak Period	0.4	5.3	-20.4	-14.7
All Periods	3.0	52.4	-33.6	21.9

Annual Toll Revenues, <i>R</i>	600.0
Annual Benefits, <i>B</i>	21.9
Stops at Manually-operated Tollgates	4.9
Annualized Cost of Toll Collection, <i>C</i>	96.6
Benefits less System Cost, <i>NB</i>	-79.6
Benefit-Cost Ratio, <i>B/C</i>	0.2
Revenue-Cost Ratio, <i>R/C</i>	6.2

2) Results of an Improved ('Optimal') Cordon Toll Scheme (i.e., an Inbound Peak Toll of NOK25 [US\$4]) vis-a-vis the Base Case of No Toll

	Savings in Operating Cost	Savings in Travel Time	Welfare Loss of Surplus	Total Benefits
Peak Periods	6.0	108.5	-19.4	95.2
Interpeak Period	0	0	0	0
Off-peak Period	0	0	0	0
All Periods	6.0	108.5	-19.4	95.2

Annual Toll Revenues, <i>R</i>	180.0
Annual Benefits, <i>B</i>	95.2
Stops at Manually-operated Tollgates	4.9
Annualized Cost of Toll Collection, <i>C</i>	70.0
Benefits less System Cost, <i>NB</i>	20.3
Benefit-Cost Ratio, <i>B/C</i>	1.3
Revenue-Cost Ratio, <i>R/C</i>	2.6

Table 3 (continued)

3) Results of a 'Perfect' (Link-based) Fully Electronic Road Pricing Scheme (i.e., a Marginal Cost Toll applied Link-by-Link vis-a-vis the Base Case of No Toll)

	Savings in Operating Cost	Savings in Travel Time	Welfare Loss of Surplus	Total Benefits
Peak Periods	7.6	162.6	-19.3	150.9
Interpeak Period	0	0	0	0
Off-peak Period	0	0	0	0
All Periods	7.6	162.6	-19.3	150.9

Annual Toll Revenues, <i>R</i>	152.1
Annual Benefits, <i>B</i>	150.9
Annualized Cost of Toll Collection, <i>C</i>	> 70.0
Benefits less System Cost, <i>NB</i>	< 80.9
Benefit-Cost Ratio, <i>B/C</i>	< 2.2
Revenue-Cost Ratio, <i>R/C</i>	< 2.2

Sources: Larsen and Ramjerdi, 1990; Ramjerdi and Larsen, 1991; Larsen, Mathieu and Ramjerdi, 1991; Ramjerdi, 1992, with corrections; and discussions with the authors.

Table 4: Benefits, Costs and Revenues of Car Ownership Fiscal Restraint Measure, Area Licensing and Electronic Road Pricing Schemes, by Vehicle Class per year compared to 1991 Reference (in millions of 1985 Hong Kong dollars)

Option	Car ownership Restraint Measure	Area Licensing Scheme	ERP Scheme A	ERP Scheme B*	ERP Scheme C	Optimum Option
Average peak-hour charge	-	HK\$7.0	HK\$8.4	HK\$9.8	HK\$9.7	HK\$10.5
Annual Benefits, B						
Private cars	-29 (-0.10)	124 (0.37)	202 (0.28)	235 (0.27)	216 (0.24)	279 (0.22)
Taxis	38 (0.13)	30 (0.09)	53 (0.07)	61 (0.07)	68 (0.07)	-21 (-0.2)
Public transport	158 (0.52)	118 (0.35)	299 (0.41)	350 (0.40)	389 (0.42)	607 (0.49)
Goods vehicles	134 (0.45)	66 (0.19)	180 (0.25)	225 (0.26)	246 (0.27)	385 (0.31)
Benefits for All vehicles	301	338	734	871	919	1250
As a Share of the Benefits of the Theoretical Optimum	[0.24]	[0.27]	[0.59]	[0.70]	[0.74]	[1.00]
Gross Revenue Generated, R	1200	188	395	465	540	976
Annualized Capital and Operating Costs of Charging Mechanisms, C	0	10 - 15	49.8	49.0	51.7	>51.7
Benefits less System Cost, NB = B-C	301	323 - 328	684	821	869	1200
Benefit-Cost Ratio, B/C	∞	22.5 - 33.8	14.7	17.8	17.8	<24.1
Revenue-Cost Ratio, R/C	∞	12.5 - 18.8	7.9	9.5	10.4	<18.9

Notes:

HK\$7.8 = US\$1 and HK\$10.1 = £1 (1985 figures).

CPI (1990)/CPI(1985) = 1.48 (Conversion factor using the Consumer Price Index for all items)

Figures in round parentheses are market shares.

* ERP Scheme B is actually the Area Pricing proposal (with slight variation) simulated in Transport Department and Wilbur, Smith and Associates (1989).

Given that ERP Schemes A, B and C increase in complexity and zone-to-zone charge levels, the simulated peak-hour charges are by-products of the simulations. Benefits include the savings in travel time and operating cost of the tolled and the disbenefits of the tolled off, hence the term 'net benefits' was used in the following sources, when referring to these benefit figures. The net benefit figure used here nets out the cost of toll collection.

Sources: Constructed from Transpotech (1985), Tables 8.5 and 8.6; and Harrison (1986), Tables 2 and 3 and text. Unpublished figures of the peak-hour charges are by courtesy of Bill Harrison.

Table 5: A Comparison of Road Use Charging Mechanisms

	MANUAL			ELECTRONIC		
Congestion Charging Mechanisms		1	2		3	4
Manual and Electronic Toll Collection plus Congestion Charging Mechanisms	Manual Toll Collection (24 hour)	Cordon Pricing (Combination of Manual and Reserved Lanes) ¹	Supplementary Licensing (Single Zone)	Electronic Toll Collection (24 hour) with AVI Technology ²	Electronic Road Pricing (ERP) with Automatic Vehicle Identification	Electronic Road Pricing (ERP) with Smart Card Technology
<i>Illustrative Case Study:</i>	Common toll plaza	Bergen Toll Ring	Singapore Area Licensing Scheme (ALS)	Oslo Toll Ring	Hong Kong ERP Scheme	Netherlands ERP Proposal
<i>From Users' Point of View (1-4):</i>						
1. User-friendliness (Simplicity)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Transparency (via <i>Ex Ante</i> Pricing)	<input type="checkbox"/>	<input checked="" type="checkbox"/> ³	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. Anonymity (Protection from Invasion of Privacy)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/> ⁴	<input type="checkbox"/>
4. Prepayment/Postpayment Option for Charging	Pay-as-you-go	Pay-as-you-go + Prepayment	Prepayment only	Prepayment/Postpayment	Prepayment/Postpayment	Prepayment ⁵
<i>From Road Authority's Point of View (5-11):</i>						
5. Enhanced Efficiency via Direct Charging	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Flexibility (Responsiveness to Demand)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ⁶	<input type="checkbox"/>
7. Reliability	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ⁷	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/> ⁸

	MANUAL			ELECTRONIC		
Congestion Charging Mechanisms		1	2		3	4
Manual and Electronic Toll Collection plus Congestion Charging Mechanisms	Manual Toll Collection (24 hour)	Cordon Pricing (Combination of Manual and Reserved Lanes) ¹	Supplementary Licensing (Single Zone)	Electronic Toll Collection (24 hour) with AVI Technology ²	Electronic Road Pricing (ERP) with Automatic Vehicle Identification	Electronic Road Pricing (ERP) with Smart Card Technology
8. Security and Enforcement: a. Protection from Theft	<input checked="" type="checkbox"/> ⁹	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/> ¹⁰
b. Protection from Fraud	<input checked="" type="checkbox"/>	<input type="checkbox"/> ¹¹	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Provision for Occasional Visitors	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/> ¹²	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
10. 'Market' Price as an Investment Signal	<input type="checkbox"/>	<input type="checkbox"/> ¹³	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. Passage of Revenue-Cost Test	Case-Specific	<input type="checkbox"/> ¹⁴ 6.3:1	<input type="checkbox"/> 6.9:1 to 11.8:1	<input type="checkbox"/> 5.9:1 to 2.2:1	<input type="checkbox"/> 7.9:1 to 10.4:1	<input checked="" type="checkbox"/> 2.6:1
<i>From Society's Point of View (12-20):</i>						
12. Passage of Benefit-Cost Test	Case-specific	i.d. ¹⁵	<input type="checkbox"/> ¹⁶	<input checked="" type="checkbox"/> ¹⁷ 0.2:1 to 2.5:1	<input type="checkbox"/> 14.7:1 to 17.8:1	<input checked="" type="checkbox"/> ¹⁸ 4.5:1
Long-run Cost per Transaction (US cents in 1990 figures)	Case-specific	11.0¢	5.6-9.9¢	21.2¢	6.6¢	¹⁹ 12.5¢
13. Minimum of Road Work and Environmental Intrusion	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ²⁰	<input type="checkbox"/>
14. Provision for Mixed Traffic	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ²¹	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
15. Handling of Transitional Phase	<input checked="" type="checkbox"/> ²²	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

	MANUAL			ELECTRONIC		
		1	2		3	4
Congestion Charging Mechanisms						
Manual and Electronic Toll Collection plus Congestion Charging Mechanisms	Manual Toll Collection (24 hour)	Cordon Pricing (Combination of Manual and Reserved Lanes) ¹	Supplementary Licensing (Single Zone)	Electronic Toll Collection (24 hour) with AVI Technology ²	Electronic Road Pricing (ERP) with Automatic Vehicle Identification	Electronic Road Pricing (ERP) with Smart Card Technology
16. Compatibility with Other Systems	<input type="checkbox"/>	<input checked="" type="checkbox"/> ²³	<input checked="" type="checkbox"/>	i.d. ²⁴	i.d.	i.d.
17. Modularity to Add-on Options (e.g. automatic route guidance)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	i.d.	i.d.	i.d.
18. Tolerance to Culture of Non-compliance	<input type="checkbox"/>	<input checked="" type="checkbox"/> ²⁵	<input checked="" type="checkbox"/>	<input type="checkbox"/> ²⁶	<input type="checkbox"/>	<input type="checkbox"/>
19. Tolerance to Varied Geography	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ²⁷	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20. Fairness and the Availability of Alternatives ²⁸	Case-specific	<input type="checkbox"/> ²⁹	<input type="checkbox"/> ³⁰	<input type="checkbox"/>	<input checked="" type="checkbox"/> ³¹	<input checked="" type="checkbox"/> ³²
Other Major Characteristics and Problems:	Land-intensive; Labor-intensive; Time-intensive (Queuing Delay)	Land-intensive; Labor-intensive; Time-intensive (Some Queuing Delay)	Labor-intensive technology; enforcement cost may be high; printing cost consideration.	Capital cost is high if the construction of large toll plazas for both electronic and manual toll collection is included. Use of AVI transponders is popular on toll roads.	Capital cost is high but the benefits are even higher; cost per transaction is low. Privacy issue is largely overcome with the use of numbered accounts.	Capital cost is high but the benefits are also high; cost per transaction is not high. Smart card technology is not yet widely commercially available.
Unweighted Index (out of 3.0)	2.0	2.0	2.2	2.4	2.6	2.4
Ranking of Congestion Charging Mechanisms ³³		4	3		1	2

Key:

Abbreviations Used:

□ - High

■ - Medium

■ - Low

ALS = Area Licensing Scheme

AVI = Automatic Vehicle Identification

ERP = Electronic Road Pricing

i.d. = Insufficient Data

Notes to Table 5:

All the figures reported in this table specifically refer to the illustrated case studies in the text.

- ¹ The variant of cordon pricing considered here is the one based on the Bergen Toll Ring, which has half of all lanes equipped with manually-operated tollgates and the other half of the lanes reserved for seasonal pass holders.
- ² Manual toll collection option is available together with electronic toll collection at the Oslo Toll Ring, hence the privacy issue does not arise.
- ³ For seasonal pass holders of the Bergen Toll Ring, the incentive to overuse passes is high once they are paid for. The same qualification applies to those holders of monthly ALS fee cards.
- ⁴ Although the Hong Kong ERP Scheme suffers from having each vehicle identified explicitly, current uses of AVI technology have largely overcome the privacy issue.
- ⁵ Although a smart card is pre-purchased, it is debited only at the moment of charging and functions like an electronic purse dispensing cash instantaneously.
- ⁶ Although ERP allows prices to be varied continuously in response to demand, 'bounded rationality' considerations on the part of decision makers call for the judicious setting of pricing gradations.
- ⁷ At the Bergen Toll Ring, some cheating occurs at the unmanned tollbooths reserved for seasonal pass holders.
- ⁸ Although smart card technology was not considered sufficiently sophisticated enough for ERP in the Dutch proposal of 1988 for four major cities, Telepass has a system for electronic toll collection based on smart cards -- operating on a limited basis on the Italian autostrada since 1989.
- ⁹ One of the principal problems with manual toll collection is the problem of the transfer of cash cages. Theft of cash and coupon books by toll operators have been reported; theft of area licenses and seasonal passes also occur.

- 10 Theft of a smart card is a problem, although the card could be made invalid when operated in conjunction
with another in-vehicle unit.
- 11 Counterfeiting of monthly licenses (or seasonal passes) is a potential problem.
- 12 Visitors from out of town will have to incur additional time in searching for outlets where area licenses
or electronic tags could be leased.
- 13 Even though Bergen Toll Ring has a 16-hour charging period, a non-zero toll still serves as an investment
signal reflecting the scarcity value of land use.
- 14 Each revenue-cost ratio reported is based on the respective charging policy of the case studies examined.
Since the revenue-cost ratios are high, i.e., low cost per dollar of revenue raised, the Norwegian schemes
-- Bergen, Oslo (and Trondheim) Toll Rings -- are all toll-financing schemes.
- 15 Despite insufficient data, it is likely that the net benefits of cordon pricing would not be high since manual
toll collection by tollbooths impedes traffic flow and causes congestion itself.
- 16 Holland and Watson (1978) report a rough estimation of the economic rate of return for the first year of
the Singapore ALS at 60% to 150%. Data from the Hong Kong ERP Project indicates that the benefit-cost
ratios for ALS in Hong Kong, if implemented, would be in the range of 22.5:1 to 33.8:1, even higher than
those of the Hong Kong ERP itself. All benefit-cost ratios are based on the specific case studies reported
in the text.
- 17 The lower bound estimate of the benefit-cost ratio is based on the actual Oslo Toll Ring, whereas the
corresponding upper bound estimate is for a 'perfect' (link-based) road pricing scheme.
- 18 The *social* benefit-cost ratio for the Dutch ERP Proposal using smart card technology is 3.2.
- 19 Despite the fact that the capital cost for smart card technology is high, the multiple transactions yield a
level of cost per transaction that is in the mid range. The annualized capital cost of a project is arrived
at by using a capital recovery factor of 0.125, corresponding to the interest rate of 8% and a project life
of 12 years.
- 20 The Hong Kong ERP Scheme required some amount of road work, whereas current AVI technologies use
gantry-mounted antennas or in-pavement antennas requiring minimal road work.
- 21 Current AVI technology allows a simple version of vehicle classification by linking an AVI transponder
with a vehicle's class. Classification equipment for heavy vehicles is available and further advances in
automatic vehicle classification (AVC) are currently being made.
- 22 Implementation of road pricing with manually-operated toll plazas is not exp^oient. Implementation of
electronic road pricing with existing electronic toll collection facilities is feasible, especially with a modular
design.
- 23 Seasonal passes and area licenses may not be compatible with other cities nearby.
- 24 Currently, there is a move to come up with an internationally agreed upon standard for AVI technology,
as part of the DRIVE project in Europe and the HRLP project in the United States, plus its integration with
automatic vehicle classification and weigh-in motion equipment.

- 25 It is expected that noncompliance will take place at the unattended nonstop reserved lanes because video enforcement is carried out only on a periodic basis to minimize cost.
- 26 Enforcement of moving vehicles under the Singapore ALS is carried out at normal traffic speeds. On the other hand, enforcement of vehicles at freeway speeds is likely to be infeasible. A good rule of thumb to use to ascertain whether a country is ready to implement ALS is the degree of its citizens' compliance with parking regulations.
- 27 Natural cordon boundaries and limited access to the city are both prerequisites to cordon pricing and ALS.
- 28 The criterion of 'fairness and the availability of alternatives' is clearly case-specific and does not apply to the charging instruments in and of itself.
- 29 The Bergen and Oslo Toll Rings both succeeded principally because the toll revenues were earmarked for road construction (80%) and busways (20%).
- 30 Without the provision of public transport and bypass routes, the Singapore ALS might not have succeeded.
- 31 Although Hong Kong has exceptionally good public transport alternatives, ERP floundered because the public *perceived* that ERP was 'just another tax', despite Government's promise that it is revenue-neutral, and their privacy might be compromised in the light of 1997.
- 32 The Netherlands' Comprehensive Road Pricing Scheme failed because the car lobby felt that it was another revenue-raising instrument and that it would place an unfair burden on those suburban residents who located where they had as a result of past government policy.
- 33 The ranking is based on an unweighted sum of the 20 criteria applied to the illustrative case studies at hand. Criteria 11, 12 and 20, in particular, pertain more to the case studies than the charging instrument method per se.

Annex 1: The Singapore Area Licensing Scheme, 1975 to present

A. Background Information

81. The Singapore Area Licensing Scheme (ALS) which began in June 1975, is the world's foremost example of road pricing. During the morning peak period of 7:30 to 9:30 a.m. (except Sundays and holidays), automobile drivers desiring to enter the Restricted Zone -- an area of over 5 kilometers square -- within the Central Business District of Singapore were required to purchase a daily or monthly license from the kiosks or post offices just outside the Restricted Zone.⁹⁹ Initially, taxis, buses, carpools (of more than four passengers) and commercial vehicles were exempt from the entry fee. The specially-shaped and color-coded licenses were priced by trial and error at around S\$3 [US\$1.25] each, with the day or month printed in large characters and displayed near the top left hand corner of the windshield. The visibility of the dated color stickers allowed traffic wardens to check them as vehicles drove by any of the gantry posts signaling the entrance to the zone at the city speed limit of 50 kph. It is the nonstop feature of the ALS -- as distinct from manually operated toll booths which also attempt to implement cordon pricing -- that is unique and reaps significant savings in travel time. The ALS is part of a comprehensive package of traffic restraint measures by the Singapore Government. Several months prior to the opening of the ALS on June 2, 1975, authorities instituted the following complementary traffic management measures in order to achieve the goal of 25% to 30% reduction in traffic volume: a) monthly parking charges in both public and private parking lots were about doubled (via mandated price increases and surcharges) and uniform hourly rates were replaced by rates which varied by geographical location and duration of stay; b) 15 park-and-ride facilities (providing about 10,000 new parking spaces) were constructed just outside the Restricted Zone to ease the switch from private to public transport; c) premium franchised shuttle bus services were provided to facilitate the transfer from the fringe parking lots to the downtown area; and d) flextime was encouraged by the government as part of a wider public

⁹⁹ The Restricted Zone has now been increased (by land reclamation) to 725 hectares (or 7.25 square kilometers). The monthly license fee is set at twenty times the daily license fee.

information campaign. After 1975, there were a couple of changes in fees, boundaries and operating hours (see Ang, 1989, Table 2). Principally, the exemption of taxis from ALS fees were rescinded (August 1, 1975) and company cars were required to pay twice the rate of private cars (January 1, 1976).

82. Beginning June 1, 1989, there was a new and major revision of the ALS: a) the restricted times of operation were extended to cover both the morning and afternoon peak periods, with the latter occurring at 4:30-7:00 p.m. (but later changed to 4:30-6:30 p.m.); b) *all* vehicles were charged, with the exception of emergency vehicles (such as ambulances, police cars and fire engines) and public buses, so that carpools were no longer exempt; c) the daily license fee for automobiles was lowered from S\$5 per day to S\$3 per peak period entry -- a (more than) 40% decrease in real charges!; and d) motorcycles were to pay one Singapore dollar per day (after July 1, 1989).

B. Analysis of Results (1975-89)

83. Even though the ALS was touted to be a resounding success, it was not free from qualifications. First, as expected from intuition, during the morning peak period, the number of motor cars dropped by three fourths within the first month whereas all vehicles dropped by between a third and a half during that period, easily surpassing the government's objectives (Toh, 1977, Table 1; Watson and Holland, 1978, Chapter 4). Second, however, as intuition would also expect, motorists rescheduled their trips to arrive during those periods just before and immediately after the restricted period, prompting authorities to extend the time period the ALS was in operation by three quarters of an hour to 10:15 a.m. on June 23, 1975. Third, simultaneously there was a significant increase in the number of taxis of about a quarter within the first three weeks, prompting authorities to remove taxis from the exempt list on August 1, 1975.⁶⁰ More importantly, a full year after ALS came into effect, there remained a decrease in private cars of three-fourths and a decrease in all vehicles of one-half, despite the fact that

⁶⁰ As a compromise, authorities lowered the fee for taxis from S\$4 to S\$2 on April 1, 1977.

there was an increase in the ALS fee of one Singapore dollar on January 1, 1976 (Seah, 1980, Table 1). Fourth, one month before ALS began, new non-uniform parking charges (rising by length-of-stay and by proximity to the CBD) -- designed as a complementary measure to area licensing -- served to raise the out-of-pocket costs of motorists (Watson and Holland, 1978, pp. 24-27, 68-73). Monthly parking fees of government car parks were also raised (by at least 20-40%) and operators of private parking lots were required to match the price increases. In addition, the government levied a surcharge equivalent to the price increase. By discouraging circular traffic within the zone in this way, public transport was made more attractive and substitutable. Fifth, the fringe parking lots to promote the park-and-ride mode -- another complementary measure to road pricing -- were deemed unsuccessful almost from inception, with only 4% of the parking spaces taken up in the first year and a half (Watson and Holland, 1978, Table 3.3). Hence the authorities promptly responded by converting the empty parking lots into hawkers' markets and cooked food stores. Sixth, the quality shuttle bus service was also a failure, with ridership well below the capacity of the buses, and so the privately operated shuttle buses were quickly merged with the regular bus system (Watson and Holland, 1978, p. 36; Wilson, 1988). Seventh, the enforcement of offenders was carried out by assigning entry point attendants (between 1 and 5) to issue traffic tickets via mail. Perhaps because of the stiff penalty of S\$50 for an offender, which is just short of the cost of a monthly license fee of S\$60, the rate of violation was only 1%-2% in 1975 (Watson and Holland, 1978, Table 3.1). Eighth, motorcycle travel -- presumably a crude substitute for private car use -- increased so much that charges for motorcycles were introduced. Ninth, as a result of a doubling of the number of carpools within the first year and annual growth occurring thereafter during the operating hours of the ALS (Seah, 1988, Table 1), and because nine-tenths of carpoolers did not make return trips in the same fashion, carpools were no longer exempt as of June 1, 1989. Tenth, the "mirror image" effect hoped for in the afternoon peak period did not materialize because of cross-town traffic in the afternoon. One third of the total trans-Restricted Zone commuting traffic chose to travel on the ring road, which serves as a bypass route; two-thirds still chose to go through the Restricted Zone after ALS was introduced. (Only one-seventh of the (two-thirds) through traffic chose to drive into the Restricted Zone during the restricted hours; the rest of the through traffic switched to a different time or made a detour by traveling on the circuitous route

in the morning peak or changed modes (Watson and Holland, 1978, p. 7)). In due course, the detours resulted in heavy traffic along the ring road around the Restricted Zone, necessitating traffic management measures such as the re-timing of traffic lights. On the other hand, on the return trips, traffic traverses directly through the relatively uncongested downtown area in the afternoon peak. Further, only about one tenth of the carpoolers were estimated to make their return trips in the same fashion (others used public transport, taxis, or were collected in private vehicles). As a result, "bumper to bumper congestion" was observed during the afternoon peak in 1983, with average traffic speed being 18 kph, in contrast to 30 kph during the morning peak (Behbehani, Pendakur, Armstrong-Wright, 1984, p. 36). Thus the morning ALS scheme was able to solve only part of the congestion problem.

C. Analysis of Results (1989-present)

84. The "mirror image" phenomenon therefore contributed directly to the extension of the restricted hours of the ALS on June 1, 1989 (from the morning peak into the afternoon peak period, initially beginning from 4:30 - 7 p.m. but later curtailed to 6:30 p.m. to accommodate business interests and activities).⁶¹

85. The most comprehensive survey to date regarding the impact of the ALS was carried out in February, 1990 by the Public Works Department and the Nanyang Technological Institute (Menon and Seddon, 1991) and the results are briefly analyzed here. One, the traffic survey indicates that there was a marked increase in total in-bound traffic immediately before and after the afternoon peak period came into operation, similar to the historical pattern during the morning peak. Further, comparisons of traffic levels traveling in and out of the Restricted Zone were made between May 1989 (which represents the pre-June 1989 scheme) and May 1990 (which represents the post-June 1989 scheme). Two, as expected, the comparisons indicate that

⁶¹ The Singapore ALS did not try out a 'tidal flow' experiment charge, in which charges are imposed on homeward bound trips out of the central business district to the suburbs in line with the main traffic flow, as opposed to the current practice of charging for entry *per se* both in the morning and the afternoon. The 'tidal flow' idea is the basis of Hong Kong's Electronic Road Pricing System Scheme B.

the total vehicle flow had decreased -- suggesting that cross-town through traffic had been curtailed -- concomitant with an increase in traffic on the ring roads. Three, both the drastic cut in daily license fee for cars and taxis plus the introduction of charging of carpools resulted in a net increase in inbound automobile traffic during the morning peak of three-tenths, relative to May 1989 (in which a high daily license fee of S\$5 previously applied). Four, a significant reduction in inbound automobile traffic of seven-tenths naturally occurs during the afternoon peak -- relative to May, 1989 (when no charges were applied at all in the afternoon peak). Five, by contrast, since goods vehicles (and motorcycles) are now charged when entering the Restricted Zone, there has been a significant reduction in these vehicles of six tenths, during both the morning and afternoon peak periods, as intuition would lead us to expect. Six, as a result of introducing the evening ALS, average traffic speed within the Restricted Zone increased to 30 kph in 1990, as indicated in the Report of the Select Committee on Land Transportation Policy (see Seventh Parliament of Singapore, 1990; Olszewski and Tan, 1991). Seven, despite a growing economy, the recent lowering of the daily license fee -- possibly the outcome of a trial-and-error pricing process -- suggests that the Singapore Government is currently using ALS as a traffic management tool to curtail congestion rather than as a revenue-generating device.

D. Financial and Economic Evaluation

86. Even though the purpose of the ALS is not to raise revenue, it fulfills the government's multipronged objective of seeking a traffic restraint measure that does not involve subsidization (Toh, 1977). From a purely financial point of view, this policy measure is appealing to local authorities, especially in an age of declining municipal funds.

87. The capital cost of the ALS is S\$6.6 million [US\$2.8 million] in 1975 and the recurrent cost for the period 1975-89 is S\$1.0 million [US\$0.4 million], including about 40 entry point attendants operating 22 gantries for enforcement purposes, in 1975.⁶² The monthly revenue

⁶² Note that the US dollar equivalent here is expressed in 1975 dollars, using the exchange rate of S\$2.40 = US\$1. The analysis that immediately follows is based on figures from Watson and Holland's (1978) study for the first year only, and the rest is computed from the data the author collected from Singapore's Public

from the sale of ALS licenses averages S\$472,000 in 1975 for the last four months. After netting out the operating costs of ticket sales, car parks and enforcement, the monthly net revenue was about S\$420,000, resulting in a net financial return to the authorities of about 76% (Watson and Holland, 1978, pp. 38-39). As a result of a one dollar increase in daily license fees on January 1, 1976, the gross revenue increased to a monthly figure of S\$568,000, which, together with comparable operating costs of S\$52,000, yield a net financial rate of return of 94%. Note that the capital cost of \$6.6 million is less than that of building an urban expressway two kilometers long (Watson and Holland, 1978, p. 37)!

88. Since the construction of car parks, bus shelters, provision of utilities and landscaping account for over nine tenths of the capital cost of the ALS, and since the park-and-ride facilities were considered a failure and converted to more productive uses, the capital cost of the ALS itself -- which is nothing more than overhead gantry structures, electric signs, and 15 or so booths for the sales of licenses -- is only S\$316,000 (Watson and Holland, 1978, Table 3.6). This means that the net financial rate of return is 1,590%, or an equivalent revenue-cost ratio of 16.9 (see also Wilson, 1988). These figures can be compared with the net financial rate of return figure calculated on the basis of data the author compiled for 1975-89. There the net financial rate of return, based on annualized capital and operating cost and annual revenue-cost ratios, comes to 590% *with* the revenues and costs of operating the car parks and 1,080% *without* the associated revenues and costs of the car parks. The difference between the 'short-term' figures collected within the first year and a half and the 'long-term' figures collected over a 14-year period can perhaps be partially explained by: a) the amortization of capital costs over a longer time period, b) the reduction in operating cost of the ALS through learning by doing, and c) the 'long-term' figures include enforcement costs hitherto not taken into account. Based on an average daily car traffic volume of 45,000 in 1989 during the morning peak period and the number of operating days of the ALS of 301 (including Saturdays) in a year, the cost per transaction comes to S12.1 cents for the period 1975-89 [US9.9 cents in 1990 figures] *with* car parks and S6.8 cents for the period 1975-89 [US5.6 cents in 1990 figure] *without* car parks.

Based on an average daily car traffic volume of 45,000 during the morning peak period and 24,000 during the afternoon peak and the number of operating days of 283 in a year, the cost per transaction comes to S16.5 cents for the fiscal year 1989 [US9.4 cents in 1990 figures] *without* car parks.⁶³ By employing the index of cost per transaction alone, the Singapore Area Licensing Scheme is among the least costly of alternative methods of charging for road use.

89. In a review of the impact of the ALS after nine years of operation, a team of World Bank researchers observed that had the ALS package of traffic management measures not been implemented, there would have been bumper-to-bumper traffic conditions universally in the Restricted Zone by 1982 (Behbehani, Pendakur and Armstrong-Wright, 1984, p. 50). Further, the deferred or canceled investments for roads amount to savings to society of the order of S\$1.5 billion.

90. The paucity of benefit-cost studies on the Singapore ALS means that it is difficult to come up with strong conclusions as to its economic viability. Holland and Watson briefly reported an economic evaluation in their 1978 article. A lower bound estimate of an economic rate of return of 15% is obtained for the first year. This figure seems to be on the low side for such a major undertaking. Nevertheless, it includes only time savings and not savings in operating costs and fuel which are normally calculated in transport projects. (Further, it does not employ the standard assumption of value of time being a function of the wage rate, but assumes that everyone has the same value of time.) Since at least three fourths (or nine tenths) of the capital cost of the scheme, which went into the construction of fringe car parks, could have been saved, the economic rate of return would have become 60% (or 150%) in the first year. The estimate here does not take into account: a) the costs to commuters of rescheduling or the loss in welfare for those tolled off the desired mode, and b) the gain in welfare to the ones who valued time highly and were tolled at the (lower) average rate upon entering the Restricted Zone.

⁶³ The difference in the number of days a year arises because the post-June 1989 scheme operated on a five and a half day a week basis. That is, $(5 + 45000/69000) \times 52 - 11 \text{ holidays} = 283 \text{ days}$.

91. In a rigorous welfare analysis, Wilson (1988) uses a joint mode choice and work start time choice model to analyze the same set of individuals surveyed in a pre- and post-ALS set of data by the World Bank. His results indicate that: a) some travelers are worse off as a result of being tolled off when entering the Restricted Zone during its operating hours and are diverted onto a different time period or even onto public transport, and having to incur the resultant rescheduling costs which exceed the payment of the ALS fee itself; b) some motorists (who used to travel, say, just outside the restricted hours) had to suffer increased congestion as a result of those motorists who were tolled off the restricted times, and those public transport commuters who had to face a more congested public transport environment following ALS would also be worse off; and c) those commuters who chose to remain *as is* and be tolled would be worse off unless their values of time savings are sufficiently high.⁶⁴ He concludes that a constant, flat-rate toll may in fact result in a decrease in social welfare as in Nash-Bentham-Sen, contrary to the "exuberant" feeling surrounding the positive results of the ALS scheme in 1975-78. Wilson simulates the effects of making various revenue-neutral assumptions by explicitly returning the toll revenues to the individuals in the sampled population and comparing the pre- and post-ALS results. However, he acknowledges that he has not taken into account incentive effects. The setting of the ALS fee in 1975-76 may have been widely observed to be on the high side and it resulted in the underutilization of the road network in the Restricted Zone. Subsequently, the ALS fee was lowered, on June 1, 1989. However, it is unclear how the simulation results would have panned out given a real decrease in daily licenses exceeding 40%.

E. Lessons for Implementing Area Licensing

92. A few lessons emerge from analyzing the Singapore ALS for the purpose of charging for congestion: a) ALS, being fairly low cost and requiring one gantry per entry point, would be suitable for cities with limited access;⁶⁵ b) ALS defers hefty investment in roads and requires

⁶⁴ Both intuition and theory suggest that these results are to be expected (see Hau, 1992).

⁶⁵ For a typical United States inner-city size of two square miles and assuming 12 major streets to a mile, the total number of pricing points or gantries needed would be 96 (or 48 if half are one-way streets). If deemed economically efficient, a few minor roads located at the cordon boundary could be closed off (as was done

very little land for its implementation, except the dozen or so kiosks for sales of licenses; c) enforcement may be difficult for high speed expressways but the level of skills required is not high, so it is suitable for a low-tech, labor-intensive society; d) ALS works best as part of a package of complementary traffic management measures such as parking pricing and the provision of viable alternatives for travelers (in the form of improved public transport, alternative modes and routes); e) since ALS is not capital intensive, it is particularly amenable to a short-term experiment, leaving few long-term repercussions; and f) ALS has worked well and should adapt itself, with any necessary modifications, to a culture that has a tradition of compliance and law enforcement.

in Singapore) to save on capital and operating costs of gantries. Further, note that ALS accommodates occasional visitors and does not require the enforcement of licenses once vehicles have entered the Restricted Zone.

Annex 2: The Manually-Operated Bergen Toll Ring, 1986 to present

A. Background Information⁶⁶

93. The Bergen Toll Ring began on January 2, 1986 within a couple of years after the scheme was first proposed. Following Singapore, it is the second city to charge motorists for entering the Central Business District (CBD). The scheme involved the construction of tollgates at six entry points to the CBD of Bergen, Norway's second largest city.⁶⁷ The tollgates are all manually operated, with about half of the lanes for motorists paying by cash or prepaid tickets and the other half reserved for motorists with seasonal passes (i.e., season tickets) placed behind the windscreen. These passes could be purchased on a monthly, six-monthly, and yearly basis, their purpose being to allow traffic to go through the tollgates at expressway speed. The enforcement of offenders is carried out by occasional videotape recording of license plates in these unattended lanes. Since its inception, the toll rates have remained at *NOK5* [*US80 cents* in 1990 figures] for light vehicles such as automobiles, with buses and light motorcycles being exempt. (Heavy vehicles are charged exactly twice the rate of light vehicles and the rate for monthly seasonal pass holders are set at 20 times the daily rate (Söderström, 1988).) The hours of operation for entry have been set at Monday through Friday, 6 a.m. - 10 p.m. (except public holidays) -- not quite daylight pricing. Note that the purpose of setting the toll at a low level is to increase revenues earmarked for road financing. (For purposes of charging for congestion, the toll rate should be higher to have a positive impact and should apply for a more selective time period. With its net toll revenue (totalling 25% of funds for a road program), Bergen was able to obtain a matching grant (25%), and when these grants are combined with regular

⁶⁶ This annex is based principally on Larsen (1987, 1988). Extensive discussions with him and insights borrowed are gratefully acknowledged.

⁶⁷ Four of the tollgates have two lanes -- one for motorists paying cash and prepaid (coupon book) tickets and another for users of seasonal passes -- and two of the parallel tollgates have four lanes -- two for cash and prepaid tickets and the other two for seasonal passes. Thus, the total number of lanes in the 6 toll plazas is 16.

government funds (50%), Bergen was able to pursue a road construction program within half the time horizon previously envisaged for its road construction program. Citing problems of congestion, air and noise pollution and traffic safety, eight tenths of toll revenues are earmarked for road construction and improvement and two tenths for bus lanes, etc. (to improve public transport).

B. Analysis of Results

94. Even though the principal purpose of the toll ring was not traffic restraint, traffic was projected to fall by 3%. Given that the overall traffic growth of 10% was due to economic growth, it was still found that the isolated (i.e., *ceteris paribus*) impact of the toll ring was that traffic declined by 6%-7% in the first year. In surveys conducted by the Institute of Transport Economics, Norwegian Centre for Transport Research (Larsen, 1987, 1988), the effects of the toll ring were found to be as follows: a) change in route choice was negligible since the topography allows almost no detours; b) there was an internal adjustment for households which are seasonal pass holders and have more than one car, resulting in more car trips undertaken since the additional toll is zero; c) it is unclear whether a change in mode choice from car to public transport had taken place; d) through traffic declined by 6-7%; e) car occupancy seems to have increased slightly; and f) changes in trip timing are observed at the end of the charging period but the effect is not significant.

95. Even though only a quarter of all vehicle owners in Bergen are holders of seasonal passes, slightly over half (55%) of the CBD-destined trips are undertaken by these holders every day.⁶⁸ In particular, seven tenths of trips during the morning rush hours are undertaken by these holders. It was found that seasonal pass holders undertake about 1.7 trips per day on average, implying an effective charge of about *NOK*2.90 [*US*46 cents], (a 40% discount or more) as compared to the standard toll rate of *NOK*5 [*US*80 cents]. From a road authority's

⁶⁸Less than one tenth of Bergen's population live inside the toll ring (Söderström, 1988).

perspective, the multiple use of seasonal passes may dampen the effectiveness of cordon pricing as a congestion charging instrument.

C. Evaluation

96. Trade-offs will have to be made either to disallow seasonal users' implicit rebates and charge directly for their entry, via tollgates, potentially exacerbating congestion and increasing operator costs, or to allow the continuation of seasonal passes with their (invaluable) nonstop nature but their zero (marginal) toll effect. *Prima facie*, it appears that the advantages of the use of seasonal passes mitigates the disadvantages of charging for congestion via tollgates. The videotaping of license plates was done on a periodic but random basis, with the number plates checked against the list of seasonal pass holders' license plates. A tolerable level of about 2% violators was found based on a 5% random check of all vehicles passing through. A fairly hefty fine equivalent to twice the monthly fee was imposed on offenders, apparently with the desired effect. The enforcement cost of monitoring motorists who cheat and the follow-up work of issuing traffic tickets are more or less covered by the revenues derived from such pursuits. Thus enforcement costs are all internalized with this approach to charging for congestion.

97. The capital cost of the system (including the construction of tollgates, consultant fees, equipment and the publicity campaign) is *NOK*12.8 million in 1986 [*US*\$2.58 million in 1990], and the operating cost (including toll operators' salaries, etc.) amounts to *NOK*7.2 million a year [*US*\$1.45 million in 1990]. The gross revenues total *NOK*55 million in 1986 [*US*\$11.10 million in 1990]. As a toll financing mechanism, the collection cost per dollar of net revenue was 19%. Since this partial dead-weight loss was lower than the high social opportunity cost of public funds estimated to be in the 30%-40% range in Norway, toll financing is therefore regarded as a viable alternative to tax financing and enhances the Toll Ring's *raison d'être*. With an average daily traffic count of 62,000 for 260 days of operation in a year, the cost per transaction (including all enforcement costs) comes to *NOK*0.546 in 1986 [*US*11.0 cents in 1990]. When compared with the Singapore ALS, the cost per transaction is only slightly higher but within the

compared with the Singapore ALS, the cost per transaction is only slightly higher but within the same order of magnitude. This is to be expected since half of all lanes were reserved for seasonal pass holders and were left unmanned. If welfare maximization is pursued in lieu of revenue maximization *per se*, then it is desirable to: a) reduce the number of operating hours, from 6 a.m. to 10 p.m. to perhaps daylight hours 6 a.m. to 5 p.m. (as is currently done in Trondheim) or to the morning and afternoon peak periods only (as in the revised Singapore ALS post-1989 period) in order to impact the modal split of truly congestion-causing traffic; and b) raise entry prices higher to effectuate a reduction in rush hour traffic. The side effects of this twin policy would most likely be an increase in revenues, both because of the relatively unresponsive (i.e., inelastic) nature of peak demands as well as the savings in toll operators' salaries. Alas, no benefit-cost studies have been performed on the Bergen Toll Ring to cross-check my intuition.

D. Lessons for Implementing Cordon Pricing via Tollgates and Reserved Lanes

98. Some lessons to be drawn from the Bergen Toll Ring of charging for congestion are as follows: a) For cities with limited entries (and detours) in developing countries such as Lagos, Bombay and Jakarta, manual charging of congestion via tollgates is potentially feasible. b) If the fraction of regular commuters is high, the use of reserved lanes for holders of seasonal passes can be justified. The use of reserved lanes would both reduce the delays that are the major drawback of cordon pricing via tollgates, and lower the capital and operating costs of the toll facility itself. c) Toll collection is a well-established technology for the construction of toll roads, tunnels and bridges, with almost universal acceptance in terms of administration. d) The use of toll revenues to finance road construction and/or public transport seems to appeal to road users as being 'fair' and appears to be a political prerequisite to implementation.

Annex 3: The Electronic and Manual Zone Fee Proposals of Stockholm, 1989 and 1992

A. The Electronic and Manual Zone Fee Proposals of Stockholm, 1989

99. In order to combat environmental pollution and congestion, the City of Stockholm proposed that a wholly electronic fee system be imposed on automobiles entering Stockholm (City of Stockholm, 1989a). The inner city is marked by a circular cordon line around it with 32 control points. In addition, a screen line with 9 control points bisects the cordon, with vehicles crossing it in any direction being charged. (Through traffic can still pass through the city without charge via certain by-pass routes). Only one charge is made each day regardless of origin or destination -- thus the concept of a day fee levied from 6 a.m. to 6 p.m., Monday through Friday. The proposed day fee of *SEK25* [*US\$4.22*] -- which is much higher than a revenue-maximizing fee in order to combat congestion -- is expected to curtail traffic by a fifth. In contrast to other systems such as the Trondheim system, in which transponders for local residents are given away free, each local motorist desiring to enter inner Stockholm is required to purchase a transponder at manufacturer's cost, estimated to be *SEK100* [*US\$16.89*] a piece. About nine tenths of motorists are estimated to be driving with purchased transponders, whereas a tenth of motorists are enforced via the video recording system and charged by arrears if they are found to be without rental transponders. It was hoped that technological development would be able to verify pictured license plate numbers electronically rather than manually. With average daily traffic of 195,000 cars and 260 operating days a year, the system cost per transaction is *SEK0.69* [*US12.7 cents*] in 1990 figures, which is higher than that of a simple AVI system for toll roads but lower than that of a combination AVI and manual system.

100. Because the electronic fee system was estimated to take a couple of years from implementation to operation, the City of Stockholm proposed a manual zone fee system, i.e., supplementary licensing, in June 1989 to serve during the transitional period (City of Stockholm, 1989b). The supplementary license was set at the same rate as that proposed for the electronic system, that is, *SEK25* [*US\$4.22*] a day. In addition, a monthly car card of *SEK300* [*US\$50.68*]

is available. It was estimated that at least 50 traffic wardens were required to monitor the nonstop traffic and a degree of compliance of only 75% was expected due to enforcement problems. The cost per transaction of *SEK*1.97 [*US*36.4 cents] in 1990 figures for the manual proposal is considerably higher than that of the electronic proposal a couple of months earlier.⁶⁹

101. In Autumn 1990, a bill was placed before the Swedish Parliament to introduce road pricing in Stockholm on an experimental basis from January 1991 to June 1993. As a result of higher petrol prices around the time of the Gulf war, and reservations about the manual zone fee proposal, the road pricing experiment was deferred until an acceptable electronic system that could protect privacy becomes available.

B. The Dennis Package, 1991-92

102. In January 1991, the three political parties in the City and County of Stockholm, who form a two-thirds majority in Parliament, signed an agreement on traffic and the environment known as the Dennis agreement.⁷⁰ They agreed that major investments totalling *SEK*28 billion [*US*\$4.73 billion] will need to be spent -- half of them are for public transport and the other half are for ring roads around Stockholm. What they had left undecided was the issue of whether or not to implement road pricing in Stockholm in 1997 and, in the Gothenburg area in 1994 (Ministry of Transport and Communications, 1991). The Swedish Parliament has adopted the principle of marginal social cost pricing -- including congestion, environment, road maintenance and accident costs. For the Stockholm region, the marginal social costs for car traffic alone are estimated to be *SEK* 10.0 billion [*US*\$1.69 billion] in 1990, of which *SEK*2.5 billion [*US*\$0.42 billion] -- only a quarter -- is collected (Tegnér, 1991). Fully three quarters of the total marginal costs are composed of congestion costs (42%) and accident costs (35%). The annual

⁶⁹ The annualized capital and operating cost and revenue figures are taken from Abbott (1990) whereas the rest of the data is from City of Stockholm, 1989b.

⁷⁰ The three major parties are the Social Democrats (which encompasses about 40% of Parliament), the Conservatives (25%) and the Liberals (10%).

net benefits of introducing marginal social cost pricing in the Stockholm region *and* combining the toll revenues with a package of ring road bypass extensions and public transport service quality improvements are estimated to be *SEK*8 billion [*US*\$1.35 billion] (Tegnér, 1991).

103. In September 1992, the three political parties reached a final agreement regarding the adoption of road use charging as an instrument to finance road investments and public transport for the Stockholm Region, which costs a total of *SEK*35.9 billion [*US*\$6.06 billion] in 1992 figures (see The Social Democratic Party, the Moderate Party and the Liberal Party, 1992). To be introduced in 1996, the uniform toll for light vehicles (weighing less than 3.5 metric tons) entering the toll ring designed to surround the city of Stockholm will be *SEK*15 [*US*\$2.53] initially whereas the average toll will be *SEK*5 [*US*84 cents] for both inbound and outbound trips on the West Link. For heavy vehicles, these so-called 'vehicle-use fees' will be three times higher (Malmsten, 1992). A total of about 25 toll stations will be situated on all roads leading to the city center and 2 toll stations will be located at the West Route. At the time of this writing, a combination of manual and electronic toll collection system -- as in the (24-hour) Oslo Toll Ring -- is planned. The fee system must be designed to satisfy the stringent requirements of security, anonymity, flexibility and the option of offering 'discounts'.

REFERENCES

- Abbott, James (1990), "Key Role for Public Transport Funding Boost in Stockholm's Road Pricing Plans," UTI, August/September, pp. 32-34.
- Ang, B. W. (1989), "Traffic Management Systems and Energy Savings: The Case of Singapore," paper presented at the ATAS Workshop on "New Energy Technologies: Transportation and Development," United Nations Centre for Science and Technology for Development, Ottawa, Canada, September 20-22, 1989, pp. 1-21.
- Ardekani, Siamak A. (1991), "Economic Evaluation of Toll Plaza Operations," paper presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., January 13-17, 1991, pp. 1-35.
- Armstrong, John (1984), "Breakthroughs in Vehicle Identification," Railway Age, pp. 40-48.
- Armstrong-Wright, Alan T. (1986), "Road Pricing and User Restraint: Opportunities and Constraints in Developing Countries," Transportation Research, Vol. 20A, No. 2, March, pp. 123-127.
- Arnott, Richard, Andre de Palma and Robin Lindsey (1991), "A Temporal and Spatial Equilibrium Analysis of Commuter Parking," Journal of Public Economics, Vol. 45, pp. 301-335.
- Ayland, Nick, Sommerville, Fraser and Steve Tarry (1990), "The Development of an Automatic Monitoring and Enforcement System," Traffic Engineering and Control, Vol. 31, No. 6, June, pp. 347-350.
- Behbehani, Redha, V. Setty Pendakur and Alan T. Armstrong-Wright (1984), "Singapore Area Licensing Scheme: A Review of the Impact," July, Water Supply and Urban Development Department, The World Bank, Washington, D.C., pp. 1-55.
- Belcher, Peter, and Ian Catling (1987), "Electronic Route Guidance by AUTOGUIDE: the London Demonstration," Traffic Engineering and Control, Vol. 28, No. 11, November, pp. 586-592.
- Bhatt, Kiran (1974), "Road Pricing Technologies: A Survey," Urban Institute Paper No. UI-1212-11, August, pp. 1-45.
- Blythe, Philip T., and Peter J. Hills (1991), "Pricing And Monitoring Electronically of Automobiles, The DRIVE Project PAMELA: 1. The Technology," Traffic Engineering and Control, Vol. 32, No. 5, May, pp. 240-245.
- Burns, Robert E. (1972), "Urban Road Pricing Through Selective Parking Taxes," Transportation Engineering Journal, Vol. 98, November, pp. 739-755.
- Carbajo, José (1992), "Regulations and Economic Incentives to Reduce Automotive Air Pollution," The Science of Total Environment, forthcoming.
- Catling, Ian (1990), "System Convergence -- The Potential for an Integrated Road Transport Environment," Vol. 17, pp. 285-299.
- Catling, Ian (1987), "Automatic Vehicle Identification," in Information Technology Applications in Transport, ed., Peter Bonsall and Michael Beli, Chapter 3, pp. 41-64, VNU Science Press BV, Utrecht, The Netherlands.
- Catling, Ian, Richard Harris and Bob McQueen (1991), "A Review of European Developments in Route Guidance and Navigation Systems," in Applications of Advanced Technologies

- in Transportation Engineering: Proceedings of the Second International Conference, Minneapolis, Minnesota, August 18-21, 1991, American Society of Civil Engineers, New York, New York, pp. 358-362.
- Churchill, Anthony (1972), in collaboration with Klaus Huber, Elke Meldau and Alan A. Walters, Road User Charges in Central America, World Bank Staff Occasional Papers Number 15, Johns Hopkins University Press, Baltimore, Maryland.
- City of Stockholm (1989a), "Proposal for an Electronic Fee System for Car Traffic in the Stockholm Inner City Area," The Streets and Traffic Administration, Stockholm, draft, pp. 1-10.
- City of Stockholm (1989b), "Zone Fee Proposal Using Car Cards," Street Department, Stockholm, pp. 1-9.
- Davies, Peter (1987), "Vehicle Detection and Classification," in Information Technology Applications in Transport, ed., Peter Bonsall and Michael Bell, Chapter 2, pp. 11-40, VNU Science Press BV, Utrecht, The Netherlands.
- Davies, Peter (1989), "Testing and Appraisal of Automatic Vehicle Identification Systems", Selected Proceedings of the Fifth World Conference on Transport Research: Transport Policy, Management & Technology Towards 2001, Yokohama, Japan, July 10-14, 1989, Vol. 11, pp. B355-B363.
- De Lozier, Edward J., (1990), "How and Why AVI?" paper presented at the International Bridge, Tunnel and Turnpike Authority International Symposium on AVI Technology for Toll Collection, New York, New York, June 17-20, 1990, pp. 1-8.
- Department of the Environment (1976), "A Study of Some Methods of Traffic Restraint: Summary Report," Research Report No. 15, Crown, United Kingdom, pp. 1-20.
- Department of Transport (1988), "Autoguide, Pilot Stage Proposals: A Consultation Document," March, United Kingdom, 38 pages.
- Downs, Anthony (1962), "The Law of Peak-Hour Expressway Congestion," Traffic Quarterly, Vol. 16, July, pp. 393-409.
- Eskeland, Gunnar S. (1992), "Attacking Air Pollution in Mexico City," Finance and Development, Vol. 29, No. 4, December, pp. 28-30.
- Foote, Robert S. (1981), "Prospects for Non-Stop Toll Collection Using Automatic Vehicle Identification," Transportation Quarterly, Vol. 35, No. 3, July, pp. 445-460.
- Greater London Council (1974), Supplementary Licensing, Greater London Council, London.
- Hackman, Lonnie, and Norene D. Martin (1969), The Parking Industry: Private Enterprise for the Public Good, National Parking Association, Inc., Washington, D.C.
- Hanks, Jr., James W., and Timothy J. Lomax (1990), "Roadway Congestion in Major Urbanized Areas: 1982 to 1988," Texas Transportation Institute, under the sponsorship of the Texas Department of Transportation, Research Report 1131-3, July, pp. 1-66, with appendices.
- Hanks, Jr., James W., and Timothy J. Lomax (1992), "1989 Roadway Congestion Estimates and Trends", Texas Transportation Institute, under the sponsorship of the Texas Department of Transportation, Research Report 1131-4, July, pp. 1-57.
- Harrison, Bil (1986), "Electronic Road Pricing in Hong Kong: 3. Estimating and Evaluating the Effects", Traffic Engineering and Control, Vol. 27, January, pp. 13-18.

- Harrison, W. J., C. Pell, P. M. Jones and H. Ashton (1986), "Some Advances in Model Design Developed for the Practical Assessment of Road Pricing in Hong Kong", Transportation Research, Vol. 20A, No. 2, March, pp. 135-143.
- Hartje, Ronald L., (1991), "Tomorrow's Toll Road," Civil Engineering, February, pp. 60-61.
- Hau, Timothy D. (1988), "Urban Transport," in The Economic System of Hong Kong, eds., Henry C.Y. Ho and Laurence L.C. Chau, Asian Research Service, pp. 190-226.
- Hau, Timothy D. (1989), "Road Pricing in Hong Kong: A Viable Proposal," Built Environment, Vol. 15, Nos. 3/4, pp. 195-214.
- Hau, Timothy D. (1990), "Electronic Road Pricing: Developments in Hong Kong 1983-89," Journal of Transport Economics and Policy, Vol. 24, No. 2, May, pp. 203-214.
- Hau, Timothy D. (1992), "Economic Fundamentals of Road Pricing: A Diagrammatic Analysis," World Bank Policy Research Working Paper Series, WPS No. 1070, December, The World Bank, Washington, D.C., pp. 1-96.
- Hensher, David A. (1991), "Electronic Toll Collection," Transportation Research, Vol. 25A, No. 1, January, pp. 9-16.
- Hills, Peter J., and Phil Blythe (1990), "Road Pricing: Solving the Technical Problems," Economic Affairs, Vol. 10, No. 5, June/July, pp. 8-10.
- Holden, David J. (1989), "Wardrop's Third Principle: Urban Traffic Congestion and Traffic Policy," Journal of Transport Economics and Policy, Vol. 23, No. 3, September, pp. 239-262.
- Holiland, Edward P., and Peter L. Watson (1978), "The Design of Traffic Pricing Schemes", Transportation Engineering, Vol. 48, No. 2, February, pp. 32-38.
- Inside IVHS, Intelligent Vehicle/Highway Systems Update, February 4, 1991; February 3, 1992 and May 26, 1992.
- Institution of Civil Engineers (1989), Congestion, Infrastructure Policy Group, London, Telford, pp. 1-100.
- Intercai BV (1989), "Functional Design Specification: Automatic Passage Charging System," Rijkswaterstaat, Projectteam Rekening Rijden, pp. 1-166.
- Jeffrey, David (1987), "Route Guidance and In-Vehicle Information Systems," in Information Technology Applications in Transport, ed., Peter Bonsall and Michael Bell, Chapter 14, pp. 319-351.
- Jones, Peter, and Arild Hervik (1992), "Restraining Car Traffic in European Cities: An Emerging Role for Road Pricing," Transportation Research, Vol. 26A, No. 2, March, pp. 133-145.
- Kulash, Damian (1974), "Parking Taxes as Roadway Prices: A Case Study of the San Francisco Experience," Urban Institute Paper No. VI 1212-9, pp. 1-46.
- Larsen, Odd I. (1987), "The Toll Ring in Bergen, Norway," Transportation Research Record 1107.
- Larsen, Odd I. (1988), "The Toll Ring in Bergen, Norway -- The First Year of Operation," Traffic Engineering and Control, Vol. 29, No. 4, April.
- Larsen, Odd I., and Farideh Ramjerdi (1990), "The Toll Rings in Norway in the Perspective of Road Pricing," paper presented at the PTRC Conference on "Practical Possibilities for a Comprehensive Transport Policy With or Without Road Pricing," London, England, December 5, 1990, pp. 1-19.

- Larsen, Odd I., and Farideh Ramjerdi (1991), "Road Pricing as a Means of Financing Investment in Transport Infrastructure, The Case of Oslo," paper appeared in "Public/Private Partnerships in Urban Mobility Proceedings," OECD/CETUR, Paris, France, April 3-5, 1991, pp. 1-17. An updated version was presented at the 71st Annual Meeting of the Transportation Research Board, Washington, D.C., January 12-16, 1992, pp. 1-12.
- Larsen, Odd I., P. Mathieu and Farideh Ramjerdi (1991), "Is 'Perfect' Road Pricing Cost Efficient?" Paper presented at Entretiens Jacques Cartier, Colloque "La régulation des déplacements urbains par leurs prix," Lyon, France, December 4-6, 1991, pp. 1-15.
- Lauridsen, Henning (1990), "The Toll Rings in Bergen and Oslo: Evolution and Experience," paper presented at the East Europe Transport Policy Seminar, Paris, France, March 18-21, 1991, pp. 1-17.
- Malmsten, Bo (1992), "Traffic and Environment in the Stockholm Region: The Greater Stockholm Negotiation ('The Dennis Package')," Stockholm Council Office of Regional Planning and Urban Transportation, Stockholm, Sweden, pp. 1-17.
- May, Anthony D. (1986), "Traffic Restraint: A Review of the Alternatives," Transportation Research, Vol. 20A, No. 2, March, pp. 109-121.
- May, Anthony D. (1991), "Demand Management: An Overview," Australian Road Research, vol. 21, No. 2, June, pp. 56-68.
- Menon, A. P. G., and P. A. Seddon (1991), "Traffic in the Central Area -- Part I: Volume Characteristics," IES Journal, The Institution of Engineers, Singapore, Vol. 31, No. 2, March/April, pp. 15-20.
- Meyer, John R., John F. Kain and Martin Wohl (1965), The Urban Transportation Problem, Harvard University Press, Cambridge, Massachusetts.
- Ministry of Transport (1964), Road Pricing: The Economic and Technical Possibilities, Her Majesty's Stationery Office, London, pp. 1-61.
- Ministry of Transport and Communications (1991), "Traffic for Growth and a Better Environment," A Summary of Provisions in Government Bill 1990/91: 87 Relating to the Audit of the Ministry of Transport and Communications, pp. 1-29.
- Ministry of Transport and Public Works (1989), "*Rekening Rijden*: Road Pricing in the Netherlands," Projectteam Rekening Rijden, (Dutch) Ministry of Transport and Public Works, Information Services, 14 pages.
- Mohring, Herbert D. (1965), "Urban Highway Investments," in Measuring Benefits of Government Investments, ed., Robert Dorfman, papers presented at a Conference of Experts held November 7-9, 1963, The Brookings Institution, Washington, D.C., pp. 231-291.
- Office of the Federal Register (1992), "Federal Highway Administration [FHWA Docket No. 92-24]: Participation in the Congestion Pricing Pilot Program," Federal Register, Vol. 57, No. 227, Tuesday, November 24, 1992, National Archives and Records Administration, Washington, D.C., pp. 55293-55298.
- Oldridge, Brian (1991), "Congestion Metering in Cambridge City," Cambridgeshire County Council, Cambridge, paper presented at the PTRC Conference on "Practical Possibilities for a Comprehensive Transport Policy With or Without Road Pricing," London, England, December 5, 1990, pp. 1-14.

- Olszewski, P., and Tan Yan Weng (1991), "Traffic in the Central Area -- Part II: Speed Characteristics," IES Journal, The Institution of Engineers, Singapore, Vol. 31, No. 2, March/April, pp. 21-28.
- Orski, C. Kenneth (1992), "Congestion Pricing: Promise and Limitations," Transportation Quarterly, Vol. 46, No. 2, April, pp. 157-167.
- Pol, Heero D. P. (1992), "Specific Design Elements: Toll Roads," Trend 90/92, Toll Collection Project, Ministry of Transport and Public Works, Rijkswaterstaat, The Netherlands, February 3, pp. 1-49 plus appendices.
- Pozdena, Randall J., Ronald Schmidt and Deborah Martin (1990), "Market-Based Solutions to the Transportation Crisis: The Concept," A Two-Part Report, Bay Area Economic Forum, May, pp. 1-17.
- Public Works Department (1990), "Electronic Road Pricing (ERP) System," Ministry of National Development, Singapore, pp. 1-8.
- Public Works Financing (1991), "SR 91 Milestones Met by CRSS," November, pp. 6-8.
- Ramirez, Anthony (1992), "Venture is Developing Ways to Speed Traffic," The New York Times, April 14, Section D, p. 5.
- Ramjerdi, Farideh (1992), "Road Pricing in Urban Areas: A Means of Financing Investment in Transport Infrastructure or of Improving Resource Allocation, The Case of Oslo," paper to be presented at the 6th World Conference on Transport Research, Lyon, France, June 29 - July 3, 1992, pp. 1-12.
- Roth, Gabriel (1991), "Private Ownership of Roads: Problems and Opportunities," paper presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., January 13-17, 1991, pp. 1-26.
- Seah, Chee-Meow (1980), "Mass Mobility and Accessibility: Transport Planning and Traffic Management in Singapore," Transport Policy and Decision Making, Vol. 1, pp. 55-71.
- Seila, Andrew F., and Paul W. Wilson (1991), "Deadweight Loss in Highway Toll Collection," Transportation Research, Vol. 25B, Nos. 2/3, pp. 127-141.
- Seventh Parliament of Singapore (1990), Report of the Select Committee on Land Transportation Policy, First Session, Parl. 1 of 1990, presented to Parliament: 2nd January, 1990, printed for the Government of Singapore by the Singapore National Printers Ltd.
- Shoup, Donald C., and Richard W. Willson (1992), "Employer-Paid Parking: The Problem and Proposed Solutions," Transportation Quarterly, Vol. 46, No. 2, April, pp. 169-192.
- Skrzycki, Cindy (1991), "AT&T, Partner Say Toll-Taking is in the Cards: Venture Offers Electronic 'Smart' Payment System," The Washington Post, December 6, 1991, p. B10.
- Smoke, Paul J. (1990), "The Procurement, Installation, and Implementation of an Electronic Toll Collection and AVI System on the Gross Ile Toll Bridge, Gross Ile, Michigan," paper presented to the International Bridge, Tunnel and Turnpike Authority International Symposium on AVI Technology for Toll Collection, New York, New York, June 17-20, 1990, pp. 60-01 to 50-09.
- Söderström, Jan (1988), "The Bergen Toll-Ring System: A Way of Financing Urgent Road Improvements by User Fees," Routes, No. 265, pp. 81-87.
- Sommerville, Fraser (1991), "Applications of Automatic Vehicle Identification Technology," Transport Reviews, Vol. 11, No. 2, pp. 173-191.

- Spock, Linda (1990), "A New Wave in Transportation," Portfolio, A Quarterly Review of Trade and Transportation, Vol. 3, No. 2, Summer, pp. 16-24.
- Stoelliorst, H. J., and A. J. Zandbergen (1990), "The Development of a Road Pricing System in the Netherlands," Traffic Engineering and Control, Vol. 31, No. 2, February, pp. 66-71.
- Tegnér, Göran (1991), "Road Pricing in Stockholm -- Some Model Simulated Experiences," paper appeared in the "Public/Private partnerships in Urban Mobility Proceedings," OECD/CETUR, Paris, France, April 3-5, 1991, pp. 1-28.
- The Chartered Institute of Transport (1990), "Paying for Progress: A Report on Congestion and Road Use Charges," published by the Chartered Institute of Transport, London, March, pp. 1-48.
- The Social Democratic Party, the Moderate Party and the Liberal Party (1992), "Agreement on Enhancing the Traffic Infrastructure in the Stockholm Region," September 29, Stockholm, Sweden, pp. 1-26.
- Thompson, Tony (1990), "Road Use Charging -- The Current State of Technology," Traffic Engineering and Control, Vol. 31, No. 10, October, pp. 526-532.
- Thorpe, Neil and Peter J. Hills (1991), "Pricing and Monitoring Electronically of Automobiles, The DRIVE Project PAMELA: 2. The Scope of Automated Pricing Systems," Traffic Engineering and Control, Vol. 32, Nos. 7/8, August, pp. 364-370.
- Toh, Rex (1977), "Road Congestion Pricing: The Singapore Experience", Malayan Economic Review, Vol. 22, pp. 52-61.
- Transport Department and Wilbur Smith and Associates (1989), Hong Kong: Second Comprehensive Transport Study, Hong Kong Government, Government Printer, Hong Kong, May 1989, pp. 1 - 10-27.
- Transpotech (1985), "Electronic Road Pricing Pilot Scheme: Main Report", May, Main Report prepared for the Hong Kong Government, pp. 1.1-4.40.
- Tretvik, Terje (1992), "The Trondheim Toll Ring: Applied Technology and Public Opinion," paper presented at the joint OECD/ECMT/GVF/NFP conference entitled "The Use of Economic Instruments in Urban Travel Management," June 18-19, 1992, Basel, Switzerland.
- U.S. Department of Transportation (1992), "A Summary of Intermodal Surface Transportation Efficiency Act of 1991: Moving America to Jobs, Homes and Market," U.S. Federal Highway Administration, FHWA-PL-92-008, Washington, D.C., pp. 1-42.
- Vickrey, William (1960), "Statement to the Joint Committee on Washington Metropolitan Problems." Transportation Plan for the National Capital Region, Hearings, Joint Committee on Washington Metropolitan Problems, November 8-14, 1959, pp. 454-490.
- Vickrey, William (1963), "Pricing in Urban and Suburban Transport," American Economic Review, Vol. 53, May, pp. 452-465.
- Vickrey, William S. (1967), "Optimization of Traffic and Facilities," Journal of Transport Economics and Policy, Vol. 2, No. 2, May, pp. 123-136.
- Watson, Peter L., and Edward P. Holland (1976), "Congestion Pricing: The Example of Singapore", Finance and Development, Vol. 13, No. 1, March, pp. 20-23.

- Watson, Peter L., and Edward P. Holland (1978), "Relieving Traffic Congestion: The Singapore Area License Scheme," World Bank Staff Working Paper No. 281, June, The World Bank, Washington, D.C., pp. 1-286.
- Waersted, K. (1992), "Automatic Toll Ring No Stop Electronic Payment Systems in Norway: Systems Layout and Full Scale Experiences," paper presented at the Sixth IEE International Conference on Road Traffic Monitoring and Control, April 28-30, 1992, London, England.
- Williams, Huw C.W.L., (1976), "User Benefit Analysis in Travel Demand Models," Journal of Regional Science, Vol. 16, No. 2, pp. 147-166.
- Willson, Richard W., and Donald C. Shoup (1990), "Parking Subsidies and Travel Choices: Assessing the Evidence," Transportation, Vol. 17, pp. 141-157.
- Wilson, Paul W. (1988), "Welfare Effects of Congestion Pricing in Singapore," Transportation, Vol. 15, pp. 191-210.
- World Bank (1972), "Transportation," Sector Working Paper, Washington, D.C., pp. 1-56.
- World Bank (1974), "Urban Transport," Sector Policy Paper, Washington, D.C., pp. 1-103.
- World Bank (1986), "Urban Transport," A World Bank Policy Study, Washington, D.C., pp. 1-61.
- Wustefeld, Norman H., (1988), "Toll Roads", Transportation Quarterly, vol. 42, No. 1, January, pp. 5-22.

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